Environment Canada
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Inland Waters Directorate
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Région de l'ouest et du nord

EVALUATION OF THE TRANSBOUNDARY TDS AND BORON WATER QUALITY OBJECTIVES FOR THE POPLAR RIVER

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SUMMARY

The International Joint Commission, in 1981, recommended that flow-weighted objectives for boron and total dissolved solids be implemented for the East Poplar River at the International Boundary, and that monitoring be undertaken to ascertain compliance with these objectives. Monitoring was initiated in January, 1981, under a Cooperative Monitoring Arrangement, and has continued to the time of this writing (mid-1989).

During 1988, Environment Canada contracted the preparation of a report with the following objectives: assess the appropriateness of using flow-weighted objectives for the East Poplar River at the International Boundary; review and document the algorithm presently being used to calculate flow-weighted concentrations and assess its suitability; assess the significance and representivity of algorithm output; and evaluate present methods of reporting compliance. Following are the report's major recommendations:

1. Flow-weighting should be discontinued, as the relationship between flow-weighted concentration and the toxic effects associated with irrigation is weak.

2. Since the likelihood of exceedance of the boron and TDS and boron objectives now appears to be small, it is recommended that the monitoring effort on the East Poplar River be reduced.

3. If flow-weighting is to be maintained, it is recommended that flow-weighted moving averages be calculated using geometric mean flows, and that the regression relationship between parameters of interest and conductance be derived from the daily conductance readings, rather than from the monthly grab sample results.

RÉSUMÉ

En 1981, la Commission mixte internationale recommandait d'appliquer des objectifs pondérés pour tenir compte du débit dans le cas de la concentration de bore et de la concentration de matières totales dissoutes dans la rivière East Poplar à la frontière internationale, et d'entreprendre des contrôles ont été entrepris en janvier 1981 dans le cadre d'un Arrangement de contrôles coopératif et étaient toujours effectués au moment de la rédaction du présent rapport (milieu de 1989).

En 1988, Environnement Canada a confié la préparation d'un rapport à un entrepreneur. Voici les objectifs de ce rapport: évaluer l'opportunité d'utiliser des objectifs pondérés pour tenir compte du débit dans le cas de la rivière East Poplar à la frontière internationale; revoir et documenter l'algorithme actuellement utilisé pour calculer les concentrations pondérées pour tenir compte du débit, et évaluer son applicabilité; évaluer la signification et la représentativité de la valeur donnée par l'algorithme; et évaluer les méthodes actuelles utilisées pour signaler si les objectifs ont été respectés. Voici les principales recommandations formulées dans le rapport:

1. Il ne faudrait plus pondérer pour tenir compte du débit, car la relation entre la concentration pondérée pour tenir compte du débit et les effets toxiques associés à l'irrigation est faible.

2. Comme il semble peu probable que les objectifs relatifs à la concentration de bore et à la concentration de matières solides dissoutes soient dépassés, il est recommandé de réduire les contrôles effectués dans la rivière East Poplar.

3. Si la pondération pour tenir compte du débit est maintenue, on recommande alors d'utiliser les moyennes géométriques du débit pour calculer les moyennes mobiles pondérées pour tenir compte du débit, et de calculer la relation de régression entre les paramètres d'intérêt et la conductance à partir de mesures de la conductance obtenues quotidiennement plutôt qu'à partir de résultats obtenus avec des échantillons prélevés au hasard mensuellement.

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1.0 INTRODUCTION

In March 1972 Saskatchewan Power Corporation (SPC) applied to the Province of Saskatchewan for permission to store and use water from the East Fork of the Poplar River (Figure 1). Permission was granted in July 1972. Construction of the storage facility (Morrison Dam and it's impoundment Cookson Reservoir) began July 22, 1975 and was completed September 18, 1976.

On September 7, 1974, SPC announced plans for the construction of a 600-megawatt coal-fired thermal-electric generating station and a new coal mine at Coronach, Saskatchewan, near the International Boundary. Construction of the first of two generating units began August 1975.

Considerable concern arose in the United States regarding potential transboundary effects relating to water quantity and quality. In April 1975 a task force was formed to consider apportionment of Poplar River water among Canadian and American users. Its 1978 report suggested that transboundary flows of the Poplar River be divided equally between Canada and the United States in accordance with a prescribed apportionment formula.

On August 2, 1977 the Governments of Canada and the United States requested that the International Joint Commission (IJC) investigate and report upon the water quality of the Poplar River, including the transboundary water quality implications of SPC activities. Among other things the IJC was to address:

- the state of Poplar River water quality, including temporal fluctuations
- the nature and location of existing and reasonably foreseeable human uses of Poplar River water

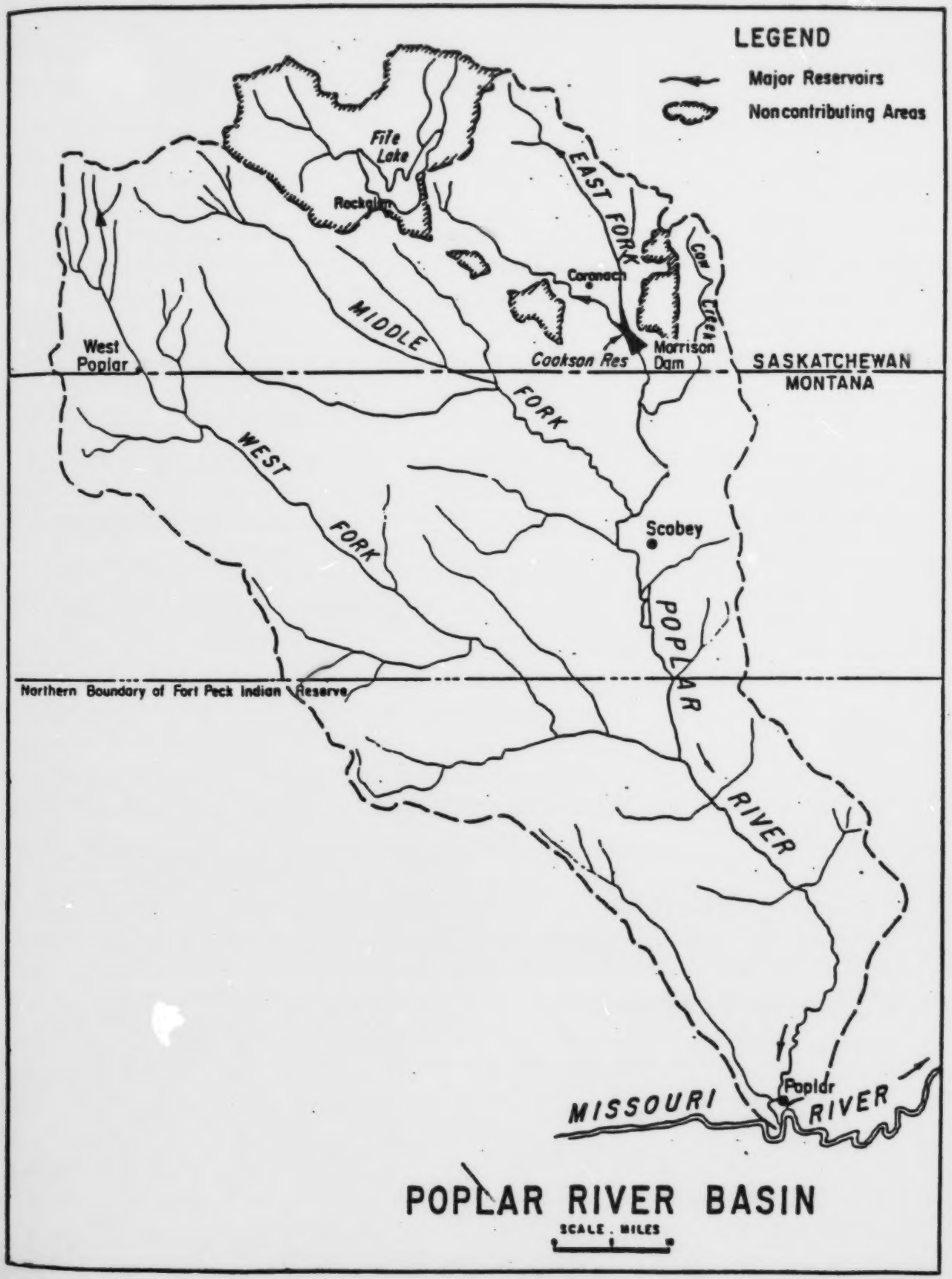

FIGURE 1.1
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- the nature, location and significance of wildlife dependent upon the Poplar River

- the effects of the water apportionment scheme and the power station on the identified uses (natural and human).

Based upon its deliberations and research the IJC recommended the following interim boron and TDS objectives:

a. For boron during the March to October period, the long-term average of the flow-weighted concentrations should be 2.5 mg l^{-1} or less in the East Fork of the Poplar River at the International Boundary, with a flow-weighted concentration not to exceed 3.5 mg l^{-1} for any three consecutive months during this period; and

b. For TDS during the March to October period, the long-term average of the flow-weighted concentrations should be 1000 mg l^{-1} or less in the East Fork of the Poplar River at the International Boundary, with a maximum flow-weighted concentration not to exceed 1500 mg l^{-1} for any three consecutive months during this period.

HydroQual Consultants was contracted to:

- assess the appropriateness of using flow-weighted objectives for the East Poplar International Station

- review and document the algorithm presently being used, to calculate flow weighted concentrations and assess its suitability

- assess the significance and representivity of algorithm output

- evaluate present methods of reporting compliance.

Assessment of the appropriateness of the flow-weighted objectives must be made in the context of the criteria used to establish them. Therefore Section 2 reviews the deliberations and research of the IJC that lead to recommendation of these objectives, and critically analyzes their appropriateness. Section 3 considers the flow-weighted algorithm that was established and considers a number of alternative methods.

2.0 DEVELOPMENT OF INTERIM OBJECTIVES AND MONITORING PROGRAM

2.1 Introduction

In order to obtain advice respecting its reference from the two federal governments, the IJC established the International Poplar River Water Quality Board (hereinafter referred to IPRWQB or the Board). In a directive from the IJC, the Board was requested to examine and report on the water quality of the Poplar River, including the transboundary water quality implications of a 600 MW thermal power station, giving consideration to chemical, physical, biological, economic, and social factors (IPRWQB, 1979). Relevant study items were to include:

- The present state of water quality, including fluctuations thereof with particular emphasis on the waters of the East Poplar River.
- The factors, both natural and man-made affecting existing water quality and their effects on water uses.
- The nature and location of existing and reasonably foreseeable water uses.
- The effects on present water quality and consequent effects on the identified uses, which would result from the following, both separately and cumulatively:
  - (a) Changes in the flow regime of the Poplar River if apportionment of the waters of the Poplar River is made as recommended by the International Souris-Red Rivers Engineering Board's Poplar River Task Force in its report of February 27, 1976 (IS-RREB), or as the Commission may otherwise recommend.
  - (b) The thermal power station of the SPC and ancillary facilities, including coal mining.
  - (c) Implementation of other reasonably foreseeable developments in either country.
- Such other matters as the Commission may indicate to the Board during the course of the study.

The Board was also asked to advise on mitigation measures which could be taken to avoid or relieve any adverse transboundary effects which could stem from the noted concerns, and to indicate the approximate costs of such measures.

To undertake the Plan of Study developed by the Board, five committees were structured. The basic tasks for the two committees germane to the surface water quality objectives were:

- The Surface Water Quality Committee - To determine the present state of water quality in the basin, including fluctuations in water quality; to determine the factors, both natural and man- made, affecting water quality and their effects on water uses; and to predict those water quality changes anticipated in the future from pollution sources and hydrologic modifications.

- The Water Uses and Water Quality Objectives Committee - To review and report on present and reasonably foreseeable uses of water, including municipal and domestic water supplies, stock watering, agricultural irrigation, industrial water needs, maintenance of fish and wildlife, and recreational uses; to examine the water quality criteria required to support the identified uses; and to develop and recommend water quality objectives to be met at the International Boundary to protect the most sensitive identified downstream uses; to examine and report on the effects of projected water quality on future uses.

The final reporting date for the Board's report and appendices was July 1, 1979.

In addition to the work of the IPRWQB and its committees other activities undertaken with the development of the interim objectives were initial public hearings, public hearings following release of the Board's report, and deliberations by the IJC and its staff. The following sections provide a brief synopsis of relevant items in the Committee and IJC reports (IPRWQB 1979a, IPRWQB 1979b, IJC 1981), other developments pertaining to finalization of the

interim objectives, and an overview of subsequent monitoring activities.

2.2 Surface Water Quality Committee Report

For the purposes of review and projections, all available data for the Poplar River basin stations were assembled, assessed, grouped to common sites where applicable, and entered into a master data base. Although some data were available from 1952-54 and 1965, most of the data considered were from the 1973-1977 period, which fortunately covered two high and two low flow years. To provide consistency, total dissolved solids (TDS) data were based on a sum of the major ions with a conversion from the bicarbonate to carbonate ion (analogous to gravimetric determinations).

Historical data were grouped by month and season (Spring - March through May; Summer - June through August; Autumn - September through November; and Winter - December through February). Much more data were available for TDS than for boron. A summary of the historical data for these parameters at the East Poplar River, International Boundary and Poplar River near Scobey (below the confluence with the Poplar River) are listed in Table 2.1.

To project water quality under different development and water use scenarios, simulations using water quantity and water quality models were carried out. For the conservative constituents, a mass balance technique was used. Some of the salient input considerations and assumptions included:

- Monthly flow balancing was assumed.
- Demand releases were made in the period June to September or June to May of the following year in proportion to irrigation requirements.

Table 2.1 Historical seasonal TDS and B values (IPRWQB, 1979a).

	Spring	Summer	Autumn	Winter
1. Total Dissolved Solids, mg l^{-1}				
East Poplar R @ Boundary				
. Before Morrison Dam Closure				
(Dec/75) Median	445	775	924	942
10th Percentile	135	612	794	758
90th Percentile	870	1488	1167	1132
. After Morrison Dam Closure				
Median	836	876	924	907
10th Percentile	471	791	871	881
90th Percentile	940	1051	989	1031
Poplar R near Scobey (before and after closure)				
Median	691	856	1001	1239
Minimum	445	222	894	908
Maximum	1378	1168	1147	1288
2. Boron, mg l^{-1}				
East Poplar R @ Boundary				
. Before Morrison Dam Closure				
Median	1.05	2.75	2.04	2.30
. After Morrison Dam Closure				
Median	1.26	1.97	1.95	1.80
Poplar R near Scobey (before and after closure)				
Median	0.65	1.60	1.60	1.65
Minimum	0.4	0.87	1.30	1.30
Maximum	1.10	2.10	2.00	1.80

- Irrigation return flows were proportioned by month and type of practice. Water spreading, initiated in March, had subsequent diminishing returns through to September. Other irrigation was maximized in August.

- A regression equation was developed to relate average monthly specific conductance to monthly flow predictions. The regression was formulated by developing an instantaneous flow/specific conductance relationship, generating specific conductance values using recorded daily flows, determining a discharge-weighted specific conductance value, and then by developing an equation relating the monthly discharge-weighted specific conductance to average monthly discharges.

- For individual conservative parameters, a regression equation with specific conductance was prepared.

Considering a proposed (and adopted) mitigation option, two generating units, and ultimate water use; projected water quality ranges (monthly) were as follows (IPRWQB, 1979b):

- Total Dissolved Solids, mg l^{-1}

	March - Sept	Oct - Feb
East Poplar R @ Boundary	970 - 1080	1070 - 1100
Poplar R near Scobey	660 - 1030	1040 - 1110

- Boron, mg l^{-1} (medians)

	Irrigation	Non-Irrigation
East Poplar R @ Boundary	3 - 3.5	4 - 5
Lower Stations	2 - 2.5	2.5 - 4

The committee recommended water quality surveillance be increased at the East Poplar River-International Boundary station and monitoring be directed by an international board.

2.3 Uses and Water Quality Objectives Committee Report

Historically, the principal uses of the Poplar River waters have been related to agriculture. Since the TDS and Boron objectives are primarily based on agricultural irrigation, comments on this use are featured.

Irrigation practices, rates and projected uses for the East Poplar River sub-basin in Montana are summarized in Table 2.2.

Multiple-purpose water quality objectives, applicable to all locations within the basin, were developed according to a plan which considered past and projected quality, causal factors, identified uses, and the optimum use of the supply. For TDS and boron, irrigation determined the requirements as follows (IPRWQB, 1979B):

	Long-Term Limit	Short-Term Limit
Boron, mg l^{-1}	5.0 (10 year)*	8.0 (3 consecutive months)**
TDS, mg l^{-1}	1000 (10 year)*	1500 (3 consecutive months)**

* Defined as the 10-year arithmetic mean of the monthly flow weighted means during the irrigation period (May 1 to September 30).

** Defined as any 3 consecutive months arithmetic mean of the monthly flow weighted means during the irrigation period (May 1 to September 30).

Table 2.2. Irrigation use summary, EAST POPLAR RIVER SUB-BASIN, MONTANA (IPRWQB, 1979b)

Type	Water Spreading (Spring)	Sprinkler (Full Service)	Flooding (Full Service)
Description	-Backflooding with spreader dykes. -Generally single -application during peak runoff period.	-Pumped above ground sprinkling system.	-Pumped or gravity diversion, overland flow.
Crops	-Pasture, cultivated	-Alfalfa, grass, hays -limited amounts of wheat and barley.	-not specified -(presumed forage)
Diversion Requirement	25.4 cm/ha	70 cm/ha* (70% n) 75.4 cm/ha* (65% n)	48.2 cm/ha/ application (2.4 applications/season)
1975: Irrigated Areas	414 ha	0	26 ha
Monthly Diversion Requirements			May 25 dam^3 June 36 dam^3 July 64 dam^3 Aug 35 dam^3 Sept 22 dam^3
1985 Projections			
- Areas	462 ha	0	38 ha
- Diversions	1171 dam^3	0	291 dam^3
2000 Projections			
- Areas	530 ha	0	91 ha
- Diversions	1344 dam^3	0	692 dam^3

* Corrected for text error.

For boron, the rationale indicated that alfalfa, the principal crop irrigated, is tolerant to levels up to 15 mg l^{-1} and production is not impaired at a 5.0 mg l^{-1} level. Barley was noted as more sensitive with projected yield reductions of 25% and 40% at boron concentrations of 5.0 and 8.0 mg l^{-1} respectively. However, it was suggested barley comprised a minor portion of the crops irrigated (0% in the East Poplar and 3.3% in the Poplar sub-basins).

A TDS objective was not made for the non-irrigation period due to low flows and general acceptability of other uses. The 1,000 mg l^{-1} level was considered suitable for all probable crops while 1,500 mg l^{-1} was indicated not to have an adverse impact provided the duration was only for a few months. The report also notes a relationship between yield reduction and leaching fraction. Literature values suggest that for alfalfa, a TDS of 1340 mg l^{-1} resulted in yield reductions of 10% and 1% at leaching fractions of 0.1 and 0.3 respectively.

The Committee recommended that the water quality objectives be reviewed every five years and monitoring be carried out to ensure objectives are not violated. Methodologies, but not frequencies or calculations, were also described.

Dissenting opinions were also presented:

- One indicated the maximum TDS should not exceed 1,000 mg l^{-1} regardless of the season.

- The second expressed concern over the boron objective and impacts on barley crops. Non-degradation of crop yield was suggested.

2.4 Board Report

The main report prepared by the Board was essentially a synthesis

of the contributing committee reports but did include some additional sources (IPRWQB, 1979). The boron issue was re-examined, and one expert noted that the soil-water concentration of 8 mg l^{-1} was critical. Using a leaching fraction of 0.30, an applied water concentration of 4 mg l^{-1} was expected to double in the soil water. Considering leaching by precipitation, the Board determined a value of 5.5 mg l^{-1} would protect alfalfa. This latter was suggested if alfalfa was to be grown in the reach between the boundary and the confluence with the Middle Fork Poplar River. The TDS objective was retained but a boron objective was not specified.

The main report also suggested that monthly monitoring be carried out for TDS and boron (with an additional synoptic survey for boron). Additionally, specific conductance was recommended for continuous surveillance.

A minority report was also attached. Among the remarks were comments on the integrity of the data and the need for further evaluation of effects of boron and total dissolved solids on crop production.

2.5 IJC Report

The IJC report to governments included consideration of the Board and Committee reports, public hearings, and supplementary submissions. During the IJC deliberations, a significant development was the modification to the SPC ash disposal system which greatly reduced the projected boron concentrations.

The boron issue and consequential impact on crops was addressed in some detail. While alfalfa was conceded to be the principal irrigated crop, other possibilities such as barley, wheat, oats, potatoes, sunflowers, and possibly waxy barley, could be irrigated. The Commission, based on the information available, including a

leaching fraction of 0.3 and a concentration factor of 2, concluded the following maximum long-term boron concentrations would fully protect the noted crops:

Crop	Boron (mg l^{-1})
Alfalfa	5.5
Barley	0.5 - 1.0
Wheat	0.5 - 1.5
Oats	2.5

A similar review for TDS yielded:

Crop	TDS (mg l^{-1})
Alfalfa	1,000 - 1,300
Barley	4,000
Wheat	4,000

A review of projections for the revised operation indicated that due to dilution impacts would largely be confined to above the Middle Fork and that projected spring (worst case) boron and TDS values under a 2-unit scenario would be 1.9 - 2.4 mg l^{-1} and 900 - 1,000 mg l^{-1} respectively.

The final commission interim water quality objective recommendations, which varied from that of the Board, were:

(a) For boron during the March to October period, the long-term average of the flow-weighted concentrations should be 2.5 mg l^{-1} or less in the East Fork of the Poplar River at the International Boundary, with a maximum flow-weighted concentration not to exceed 3.5 mg l^{-1} for any three consecutive months during this period; and

(b) For TDS during the March to October period, the long-term average of the flow-weighted concentrations should be 1,000 mg l^{-1} or less in the East Fork of the Poplar River at the International Boundary, with a maximum flow-weighted concentration not to exceed 1,500 mg l^{-1} for any three consecutive months during this period.

The Commission suggested the long-term concentrations be calculated as five year rolling averages and that they be based on mean monthly flows with at least one boron and one TDS sample to be taken at intervals of not more than 31 days during the March to October period.

The final IJC objective recommendations were altered in varying degrees from committee and Board suggestions. The rationale was not clearly defined in the report. Significant factors and/or inferred or suggested reasoning were as follows:

- Flow-weighting was retained to avoid problems when the flow was primarily groundwater discharge. Except for spring floods, which spill from Cookson Reservoir, the flow weighting would reflect demand releases when water would be used for irrigation purposes.
- The periods under consideration were extended to March through October (from May through September). This would be the maximum period for any irrigation use.
- Objective boron concentrations were substantially reduced. The levels would protect irrigated alfalfa above the Middle Fork and probably, with some inflow dilution from the Middle Fork, minimize yield loss of barley irrigated in the lower reach. The change in the project (ash disposal system) and constraints imposed by Saskatchewan significantly decreased projected boron inputs to the system.
- The long-term period was reduced from 10 years to 5 years.

The commission further recommended:

- Establishment of a bilateral group to monitor water quantity and quality.
- Field experiments be carried out to assess crop impacts from boron and TDS.
- Consideration be given to recommending objectives based on the combined flows of the East and Middle Forks.

The latter two points have apparently not been addressed. Prior to release of the IJC report, bilateral discussions resulted in the September 1980 formation of a Co-operative Monitoring Arrangement among Canada, United States, Saskatchewan, and Montana.

2.6 Poplar River Bilateral Monitoring Committee Activities

The Poplar River Bilateral Monitoring Committee formed in 1980 was intended to: ensure exchange of monitoring data, review data and present annual reports, review monitoring systems to ensure adequacy, and recommend any modifications to established monitoring schedules (PRBMC, 1987). The original five-year mandate was subsequently extended.

Based on a review of the 1981 to 1986 calendar year annual reports, the following TDS/boron monitoring and data management developments were noted:

1981
- Two grab samples (by the United States Geological Survey (USGS) and Environment Canada) per month were collected. Although daily flow records were available, the committee felt the data base unsatisfactory for the computation of monthly flow-weighted concentrations. Hence only instantaneous data were used for the water quality assessment. Three-month moving-averages were based solely on concentration values.

1982
- Additional (daily) conductivity data (March to October) were collected by the USGS.

- Regression equations were developed for TDS/specific conductance and boron-conductance.

- Flow-weighted concentrations were calculated using mean-daily flows and instantaneous daily concentrations

(computed from the specific conductance regressions).

- Long-term objective comparisons were presented as a five-year moving-average of March to October data advanced in monthly increments. The resulting data were plotted at the mid-point of the five-year period.

- Short-term objective comparisons used three-month (90-day) moving flow-weighted concentrations advanced one day at a time over the March through October period.

- Data compatability exercises between Environment Canada and USGS were carried out.

1983 - Inter-agency quality control was continued.

- TDS and boron concentrations for flow-weighting purposes were calculated from a regression relationship with specific conductance.

- Short-term objectives were tested by calculating three-month (90-day) moving flow weighted concentrations advancing a month at a time.

- Long-term (five-year) moving-averages utilized data for an entire year.

1984 - Inter-agency quality control indicated differences in boron results.

1985 - Further inter-agency data compatibility work identified TDS and boron differences.

1986 . Quality control interchange continued and showed some improvement.

It should be noted that cumulative data were used to annually generate the regression relationships, and therefore the equations change on an annual basis.

3.0 CURRENT DATA COLLECTION AND INDICATOR ASSESSMENT PROCEDURES

3.1 Introduction

In this section we document the data handling procedures implemented to assess compliance with the boron and TDS standards. We review data acquisition for this purpose (Section 3.2), the computational methods which are being used (Sections 3.3 and 3.4), alternative computational schemes (Section 3.5), the behaviour of moving averages (Section 3.6), the effects of flow regime (Section 3.7), relevance of the objectives to irrigated-crop protection (Section 3.8) and the appropriateness of flow weighting in the objectives.

3.2 Data

3.2.1 Daily Observer Data

A sampling and stream gauging station has been established on the East Fork Poplar River at the International Boundary. Since February 16, 1982 (with the exception of November and December 1982) it has been sampled daily by a local observer who sends a grab sample to the USGS Laboratory in Denver for conductivity measurement (Figure 3.1). Mean daily flows (Figure 3.2) are estimated from the gauge data (Water Survey of Canada).

3.2.2 Grab Sample Data

Since August 1975, on an approximately monthly basis, the Canadian Department of Environment and the U.S.G.S. have collected East Poplar River grab samples for laboratory analyses of boron and TDS concentrations (Figures 3.3 and 3.4), and specific conductance. Between July 1974 and August 1975 a few intermittent analyses were also performed.

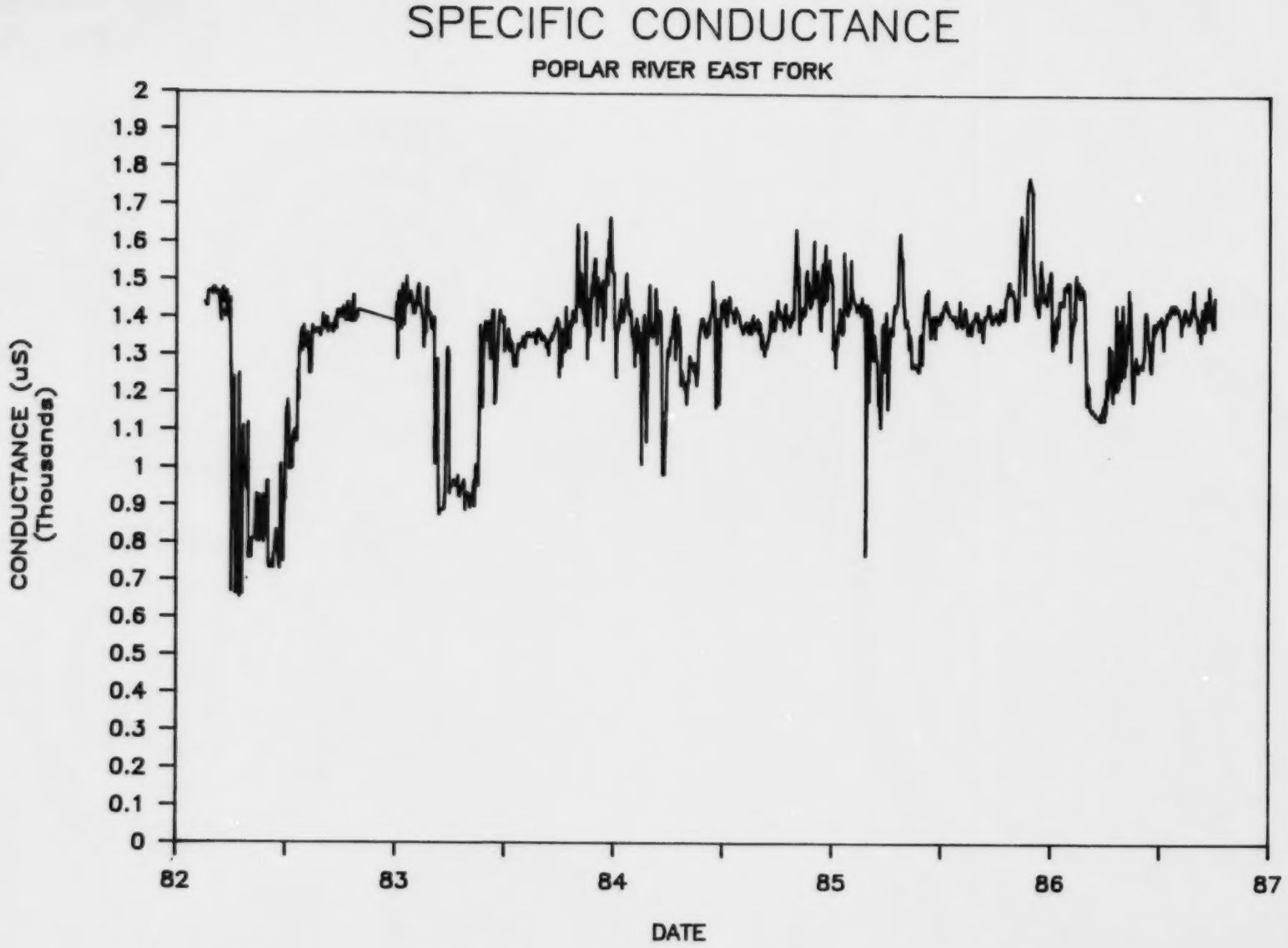

FIGURE 3.1
HydroQual

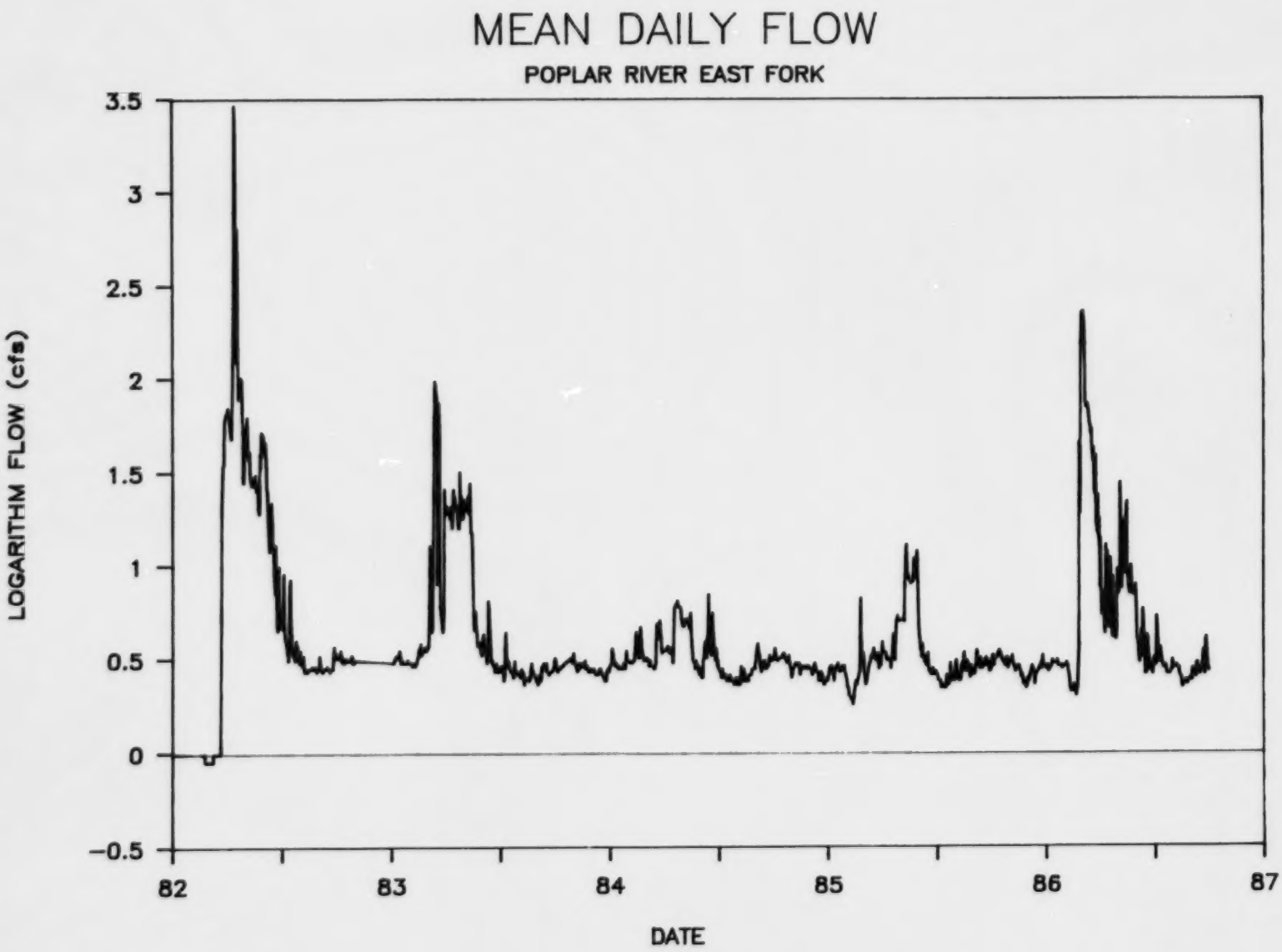

FIGURE 3.2
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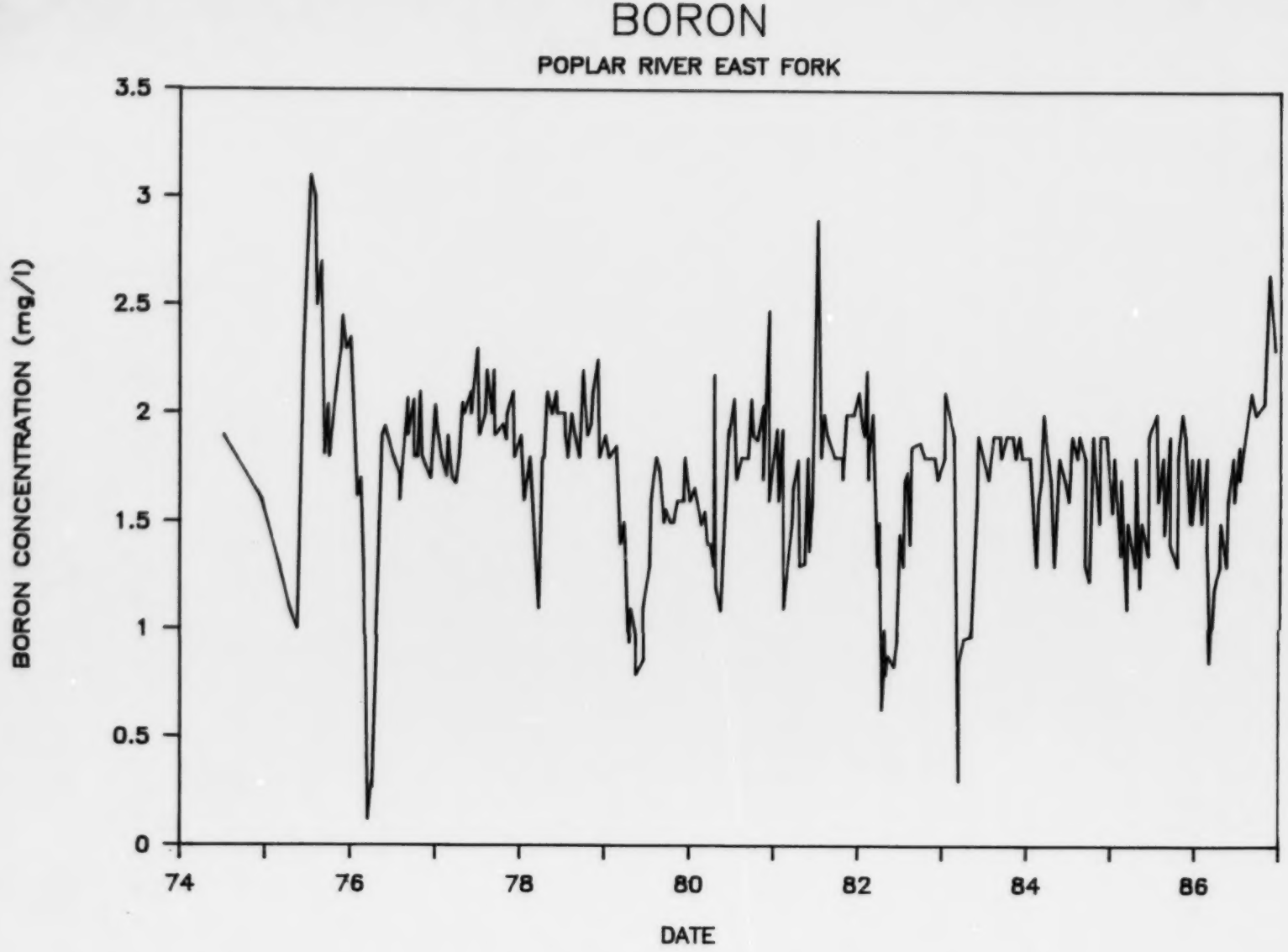

FIGURE 3.3
HydroQual

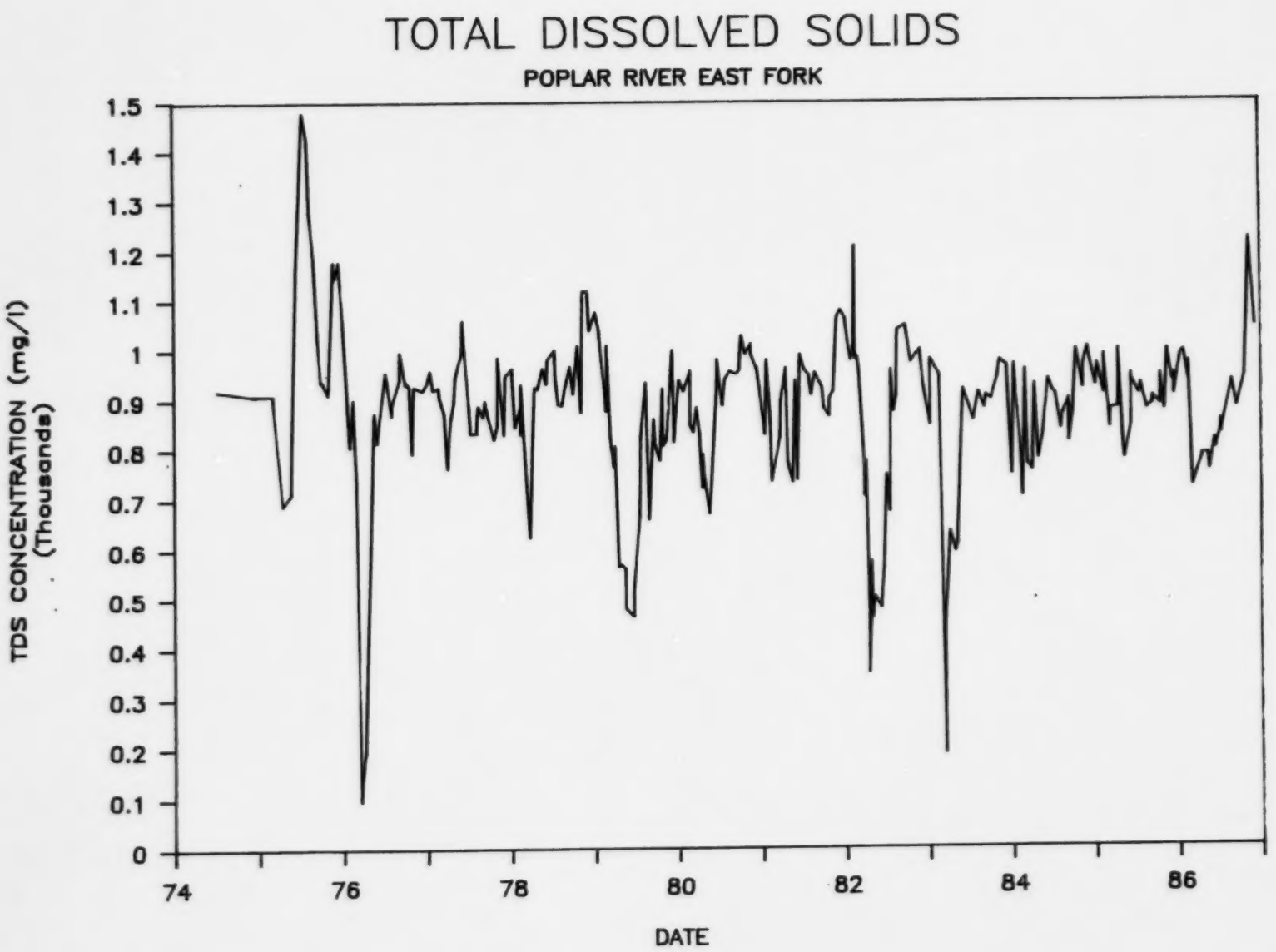

FIGURE 3.4
HydroQual

3.2.3 Data Exchange

The data obtained by both countries are exchanged and quality assurance checks are undertaken annually to ensure comparability between analytical laboratories.

3.3 Grab-Sample Data Computation

To illustrate the computations being performed using the grab-sample data, we work through examples from the 1986 data (Tables 3.1 and 3.2). The methods presented were translated directly from the computer programs used. (See Section 3.6 for the meaning of "filter" as used in the present section.)

3.3.1 Flow-weighted Monthly Mean

STEP	OPERATION
1.	For each date, each boron and TDS concentration is multiplied by that date's flow, yielding a flow-weighted concentration (or loading).

e.g. Boron

14 Jan 86 1.80 x 3.00 = 5.40

28 Jan 86 1.50 x 2.90 = 4.35

TDS

14 Jan 86 990 x 3.00 = 2970

28 Jan 86 996 x 2.90 = 2888

2. Within each month the flow-weighted boron concentrations, the flow-weighted TDS concentrations and the flows on the sample dates are each summed.

Table 3.1 Grab-sample data from the Poplar River East Fork, for the year 1986.

DATE	SOURCE	BORON (mg 1-1)	TDS (mg 1-1)	FLOW (cfs)	CONDUCT (uS)
14 Jan 86	USA	1.80	990	3.00	1490
28 Jan 86	CAN	1.50	996	2.90	1490
18 Feb 86	USA	1.80	940	2.20	1530
18 Feb 86	CAN	1.40	974	2.20	1460
07 Mar 86	CAN	0.85	725	155.00	1120
24 Mar 86	USA	1.20	750	24.00	1150
16 Apr 86	USA	1.30	780	4.60	1200
17 Apr 86	CAN	1.50	788	4.90	1260
15 May 86	USA	1.30	790	15.00	1240
20 May 86	CAN	1.60	757	7.40	1350
12 Jun 86	CAN	1.80	819	5.80	1340
17 Jun 86	USA	1.60	800	2.60	1220
08 Jul 86	CAN	1.85	840	3.30	1320
08 Jul 86	USA	1.70	830	3.30	1230
08 Jul 86	CAN	1.80	857	3.30	1330
08 Jul 86	USA	1.70	830	3.30	1230
08 Jul 86	CAN	1.85	854	3.30	1334
08 Jul 86	USA	1.70	830	3.30	1230
27 Aug 86	CAN	2.10	935	2.40	1430
18 Sep 86	CAN	2.00	883	2.70	1425
23 Oct 86	CAN	2.05	946	2.60	1492
13 Nov 86	CAN	2.65	1223	2.30	1870
10 Dec 86	CAN	2.30	1047	2.40	1630

Table 3.2 Results of calculations performed on the grab-sample data.

DATE	MONTHLY FLOW-WEIGHTED MEAN CONCENTRATION		MONTHLY MEAN FLOW	MONTHLY FLOW TOTAL	THREE MONTH MOVING AVERAGE	
	BORON ($mg\ l^{-1}$)	TDS ($mg\ l^{-1}$)	(csf)	(csf)	BORON ($mg\ l^{-1}$)	TDS ($mg\ l^{-1}$)
Jan 86	1.65	993	2.95	5.90	1.62	961
Feb 86	1.60	957	2.20	4.40	0.94	742
Mar 86	0.90	728	89.50	179.00	0.94	736
Apr 86	1.40	784	4.75	9.50	0.97	736
May 86	1.40	779	11.20	22.40	1.47	787
Jun 86	1.74	813	4.20	8.40	1.54	798
Jul 86	1.77	840	3.30	19.80	1.84	852
Aug 86	2.10	935	2.40	2.40	1.94	881
Sep 86	2.00	883	2.70	2.70	2.05	920
Oct 86	2.05	946	2.60	2.60	2.21	1007
Nov 86	2.65	1223	2.30	2.30		
Dec 86	2.30	1047	2.40	2.40		

e.g.

	Boron	TDS	Flow
14 Jan 86	5.40	2970	3.0
28 Jan 86	4.35	2888	2.9
Jan 86 TOTALS	9.75	5858	5.9

3 Each of the monthly constituent totals are divided by the monthly flow total, yielding the monthly flow-weighted mean concentration.

e.g.

	Boron	TDS
Jan 86	9.75/5.9 = 1.65	5858/5.9 = 993

These concentrations are recorded in Table 3.2.

4 To estimate monthly mean flow each month's flow total is divided by the number of items in the sum. Note that this estimate is based upon the number of grab samples taken, not the number of days in the month.

e.g. Jan 5.9/2 = 2.95

3.3.2 Three-Month Moving-Average Filter

STEP OPERATION

1 Each month's flow-weighted mean concentration (Table 3.2) is multiplied by its monthly mean flow producing a monthly loading.

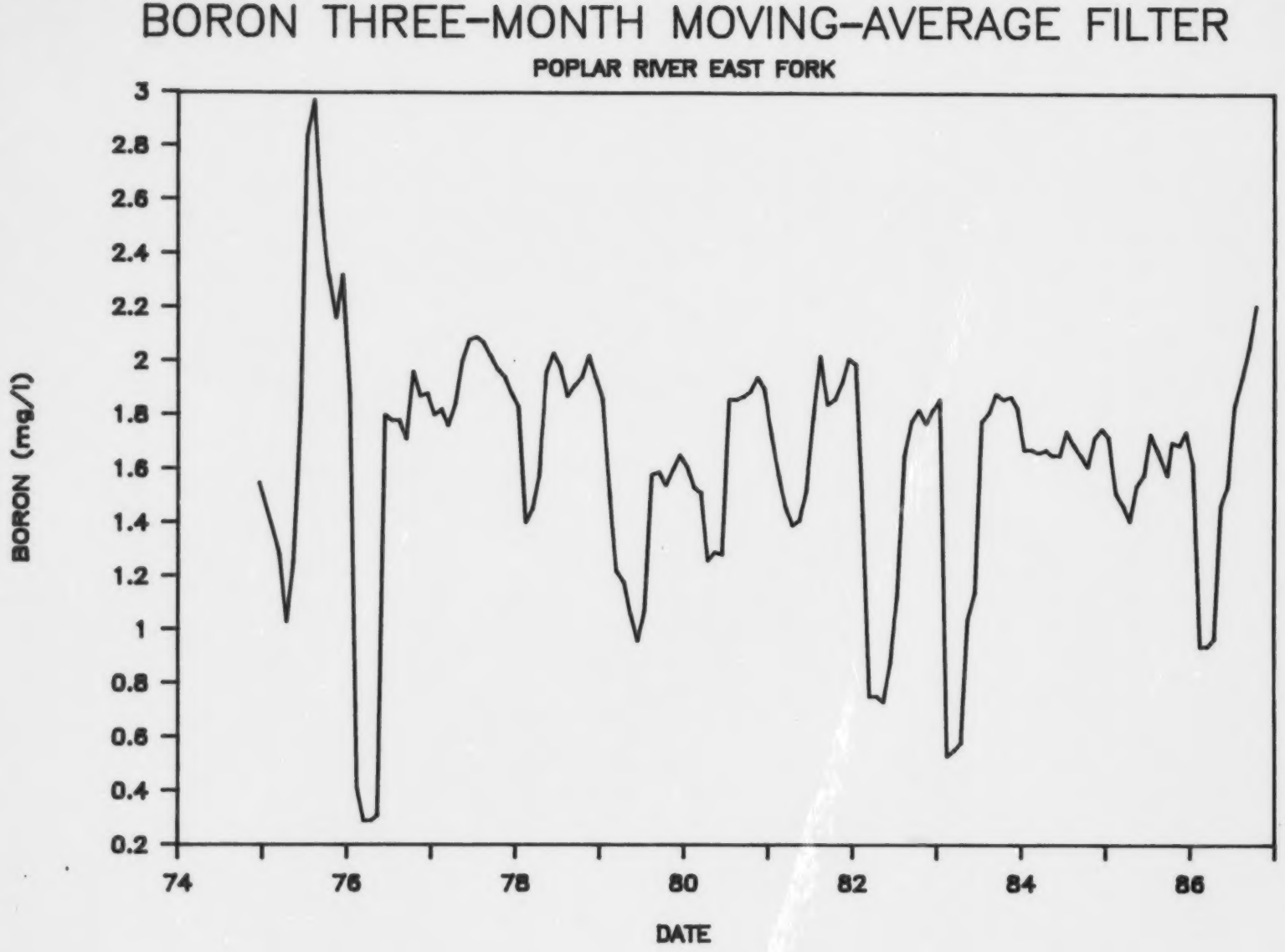

FIGURE 3.5
HydroQual

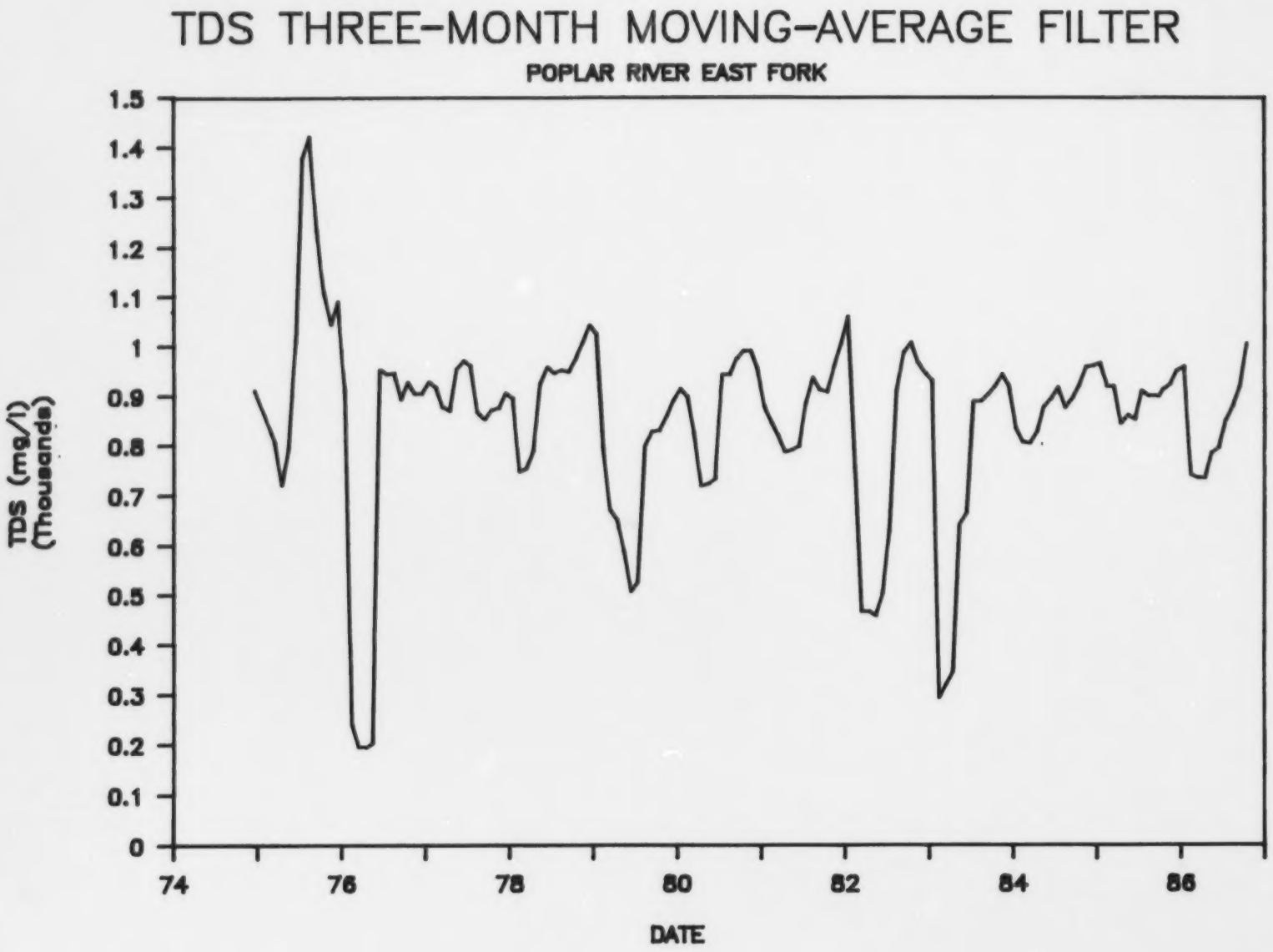

FIGURE 3.6
HydroQual

e.g.	Boron		Flow		Loading
Jan	1.65	x	2.95	=	4.87
Feb	1.60	x	2.20	=	3.52
Mar	0.90	x	89.50	=	80.55
Apr	1.40	x	4.75	=	6.65

2 For each group of three consecutive months:

- the loadings obtained in Step 1 above are summed
- the monthly mean flows for the period are summed
- the sum of loadings is divided by the sum of flows

e.g.

Group			3-month average
Jan to March	$\frac{4.87 + 3.52 + 80.55}{2.95 + 2.2 + 89.5}$	=	0.94
Feb to April	$\frac{3.52 + 80.55 + 6.65}{2.2 + 89.5 + 4.75}$	=	0.94

3 Each three-month average is recorded on the line of the table corresponding to the centre month (Table 3.2).

4 The three-month moving average is plotted versus the date of the centre month (Figures 3.5 and 3.6).

These four steps are summarized in the equation:

$$A_3 = \frac{\sum_{i=1}^{3} C_i Q_i}{\sum_{i=1}^{3} Q_i} \qquad (3.1)$$

where A_3 is the three-month flow-weighted moving average, C_i is the flow-weighted mean concentration for month i, and Q_i is the mean of the measured flows for month i (see note in Step 4, Section 3.3.1).

3.3.3 Five-Year Moving-Average Filters

A five-year moving-average filter is computed similarly to the three-month moving-average filter except its range spans 61 consecutive months rather than three consecutive months (Figures 3.7 and 3.8).

3.4 Computations on Observer Daily Data

Between February 1982 and the end of September 1986 (the end of the period for which we were provided data for this report), the observer at the International Boundary had provided approximately 1625 specific conductance data records. In this section we outline and comment upon the calculations used to analyze these data.

3.4.1 Predicting Boron and TDS from Specific Conductance

The observer's samples provide specific conductance but not boron or TDS concentrations. It was therefore necessary to devise a method of predicting these two variables from the specific-conductance reading. This was accomplished by regressing the laboratory specific-conductance estimates from the periodic grab samples on their corresponding estimates of boron and TDS

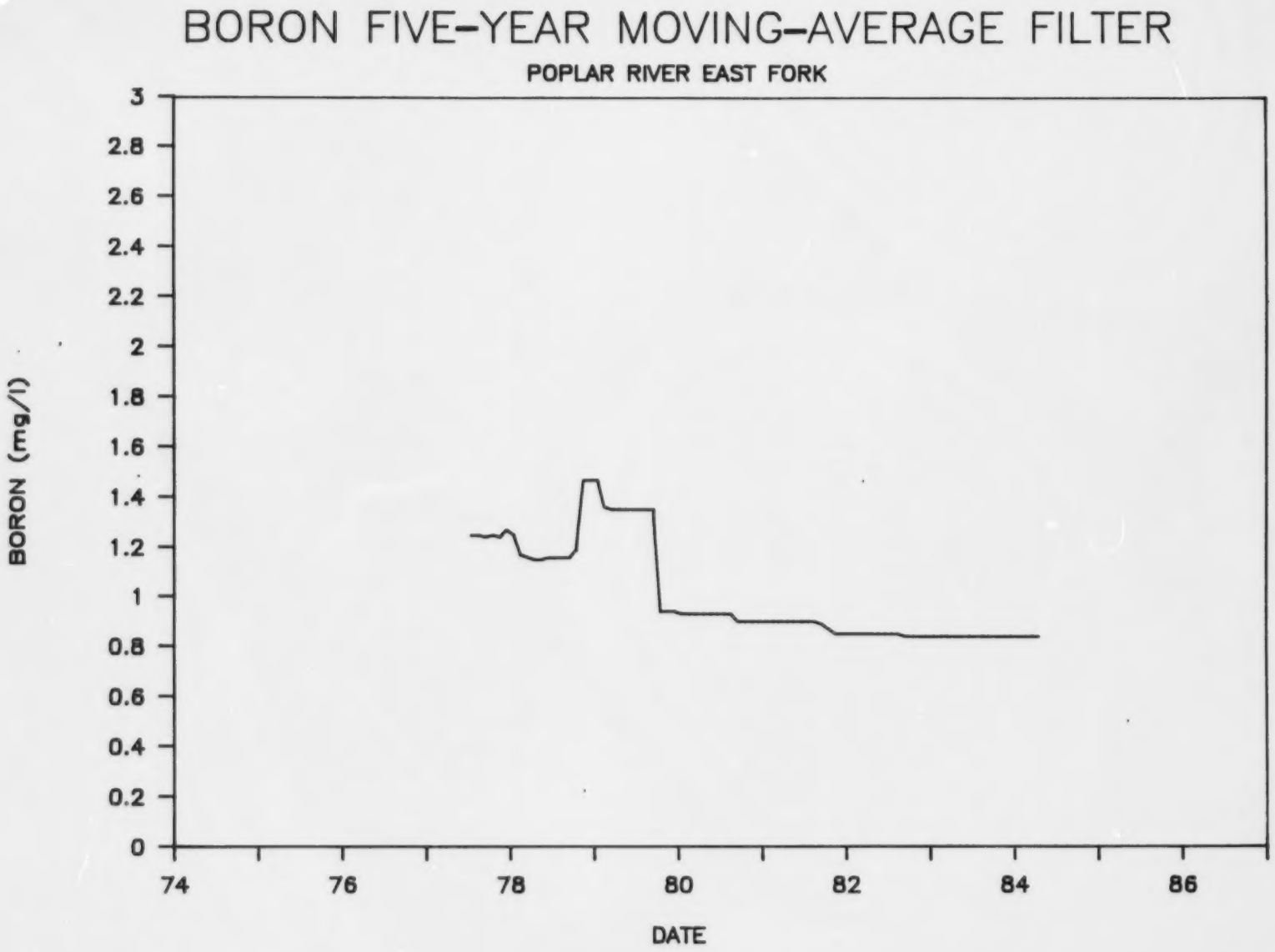

FIGURE 3.7
HydroQual

TDS FIVE-YEAR MOVING-AVERAGE FILTER

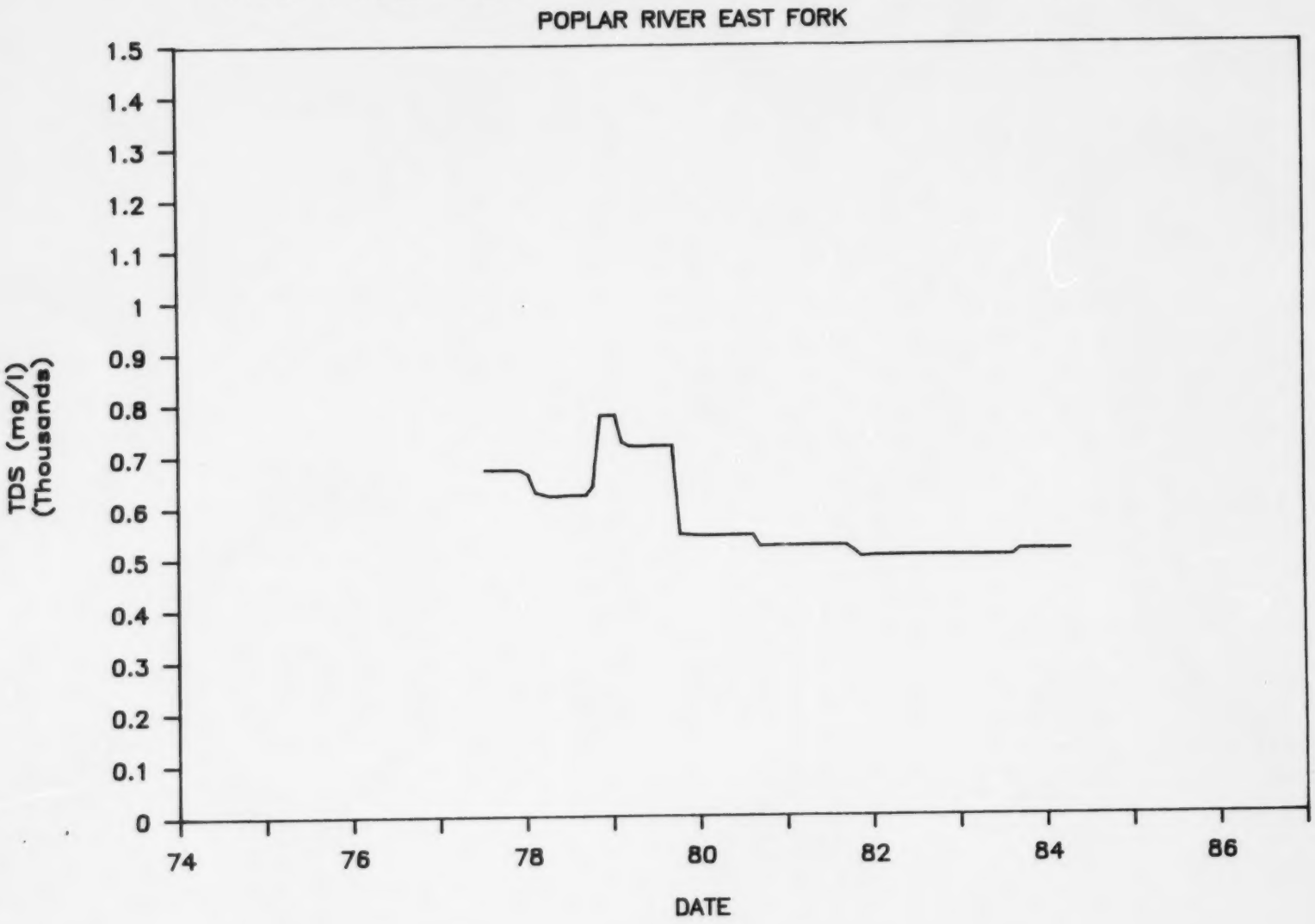

FIGURE 3.8
HydroQual

Table 3.3 Regression statistics for the fits of boron (mg 1-1) and total dissolved solids (mg 1-1) on specific conductance (uS) for the years 1974 to 1986. Inspection of probabilities associated with the statistics (t) for each coefficient indicate that all slopes are significantly different form zero ($p < 0.05$) as are the intercepts for boron. The intercepts for total dissolved solids are not significantly different from zero ($p > 0.05$).

BORON PREDICTOR EQUATIONS

VARIABLE	COEFFICIENT	STD ERROR	t	TWO-TAILED PROBABILITY
INTERCEPT	-0.204	0.077	-2.651	0.009
SLOPE	0.0014381	0.564	25.475	0.000
	YEARS: 1974-1982	N: 188	r SQUARED:	.986
INTERCEPT	-0.267	0.067	-3.970	0.000
SLOPE	0.0014793	0.499	29.663	0.000
	YEARS: 1974-1983	N: 214	r SQUARED:	.986
INTERCEPT	-0.267	0.068	-3.934	0.000
SLOPE	0.0014684	0.502	29.254	0.000
	YEARS: 1974-1984	N: 242	r SQUARED:	.986
INTERCEPT	-0.253	0.071	-3.562	0.000
SLOPE	0.0014415	0.522	27.636	0.000
	YEARS: 1974-1985	N: 269	r SQUARED:	.984
INTERCEPT	-0.268	0.070	-3.826	0.000
SLOPE	0.0014527	0.514	28.241	0.000
	YEARS: 1974-1986	N: 292	r SQUARED:	.984

Table 3.3 (continued)

TOTAL DISSOLVED SOLIDS PREDICTOR EQUATIONS

VARIABLE	COEFFICIENT	STD ERROR	t	TWO-TAILED PROBABILITY
INTERCEPT	20.917	24.874	0.841	0.401
SLOPE	0.6381767	182.186	35.029	0.000
	YEARS: 1974-1982	N: 188	r SQUARED:	.994
INTERCEPT	8.457	21.673	0.390	0.697
SLOPE	0.6462192	160.845	40.177	0.000
	YEARS: 1974-1983	N: 214	r SQUARED:	.994
INTERCEPT	8.178	21.432	0.382	0.703
SLOPE	0.6436385	158.397	40.635	0.000
	YEARS: 1974-1984	N: 242	r SQUARED:	.995
INTERCEPT	10.584	20.588	0.514	0.608
SLOPE	0.6402801	151.206	42.345	0.000
	YEARS: 1974-1985	N: 269	r SQUARED:	.995
INTERCEPT	10.526	19.655	0.536	0.593
SLOPE	0.6399514	144.247	44.365	0.000
	YEARS: 1974-1986	N: 292	r SQUARED:	.995

concentrations. These regressions are updated annuallyas new data are added to the data base.

We regressed boron and TDS on specific conductance for each of the data sets that would have been available at the end of each year from 1982 to 1986 (Table 3.3). The equations for boron all had significant slopes and intercepts, but for TDS none of the intercepts was significantly different from zero.

Plots of residuals after regression versus the independent variable should show a uniformly wide horizontal distribution of points if the linearity, additivity and homoscedasticity (equal variation of the data along the regression line) assumptions of linear regression have been fulfilled. The residual plots (Figures 3.9 and 3.10) for the data (1974 to 1986) show horizontal distributions as is appropriate, but the distributions are not of uniform width, being broadest (vertically) near their centres, and narrow towards extreme values of specific conductance. There are two possible reasons for this feature:

1) The assumption of homoscedasticity may have been violated and therefore the regressions are suspect. It is common for the variance of the concentrations of dissolved constituents to increase with increasing specific conductance, consequently the residuals after regression demonstrate a corresponding increase. This can result in a poor estimate of the slope of the regression line since it can be greatly influenced by the position of a few data points associated with high specific conductance. With the present data this effect does not appear to have occurred, but in future a few of these high leverage points may be obtained and be influential. It is therefore strongly recommended that plots of residuals after regression be carefully scrutinized for this effect. If it occurs, the distribution of residuals would tend away from the horizontal. A possible remedy in that instance may be a transformation,

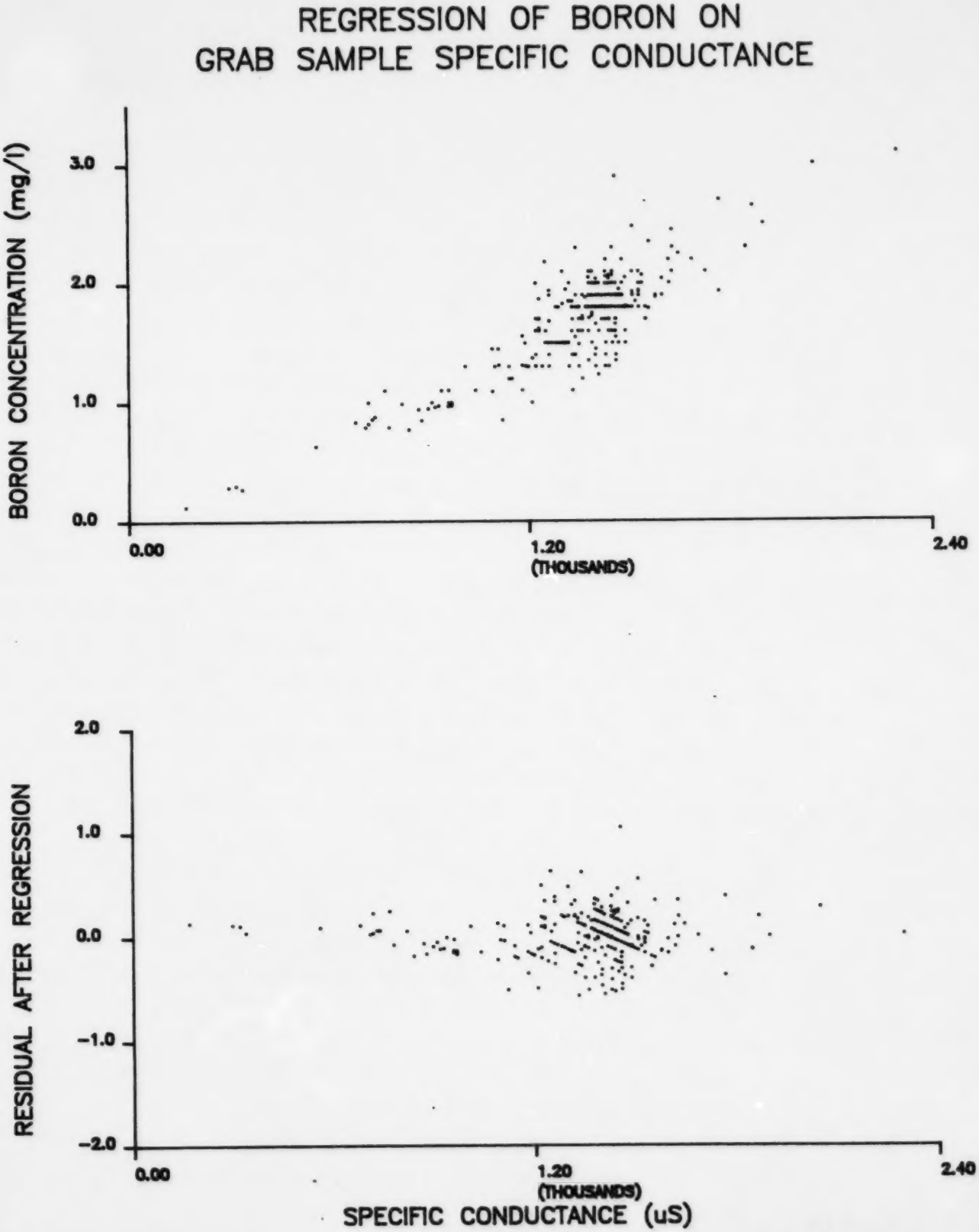

FIGURE 3.9
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REGRESSION OF TDS ON GRAB SAMPLE SPECIFIC CONDUCTANCE

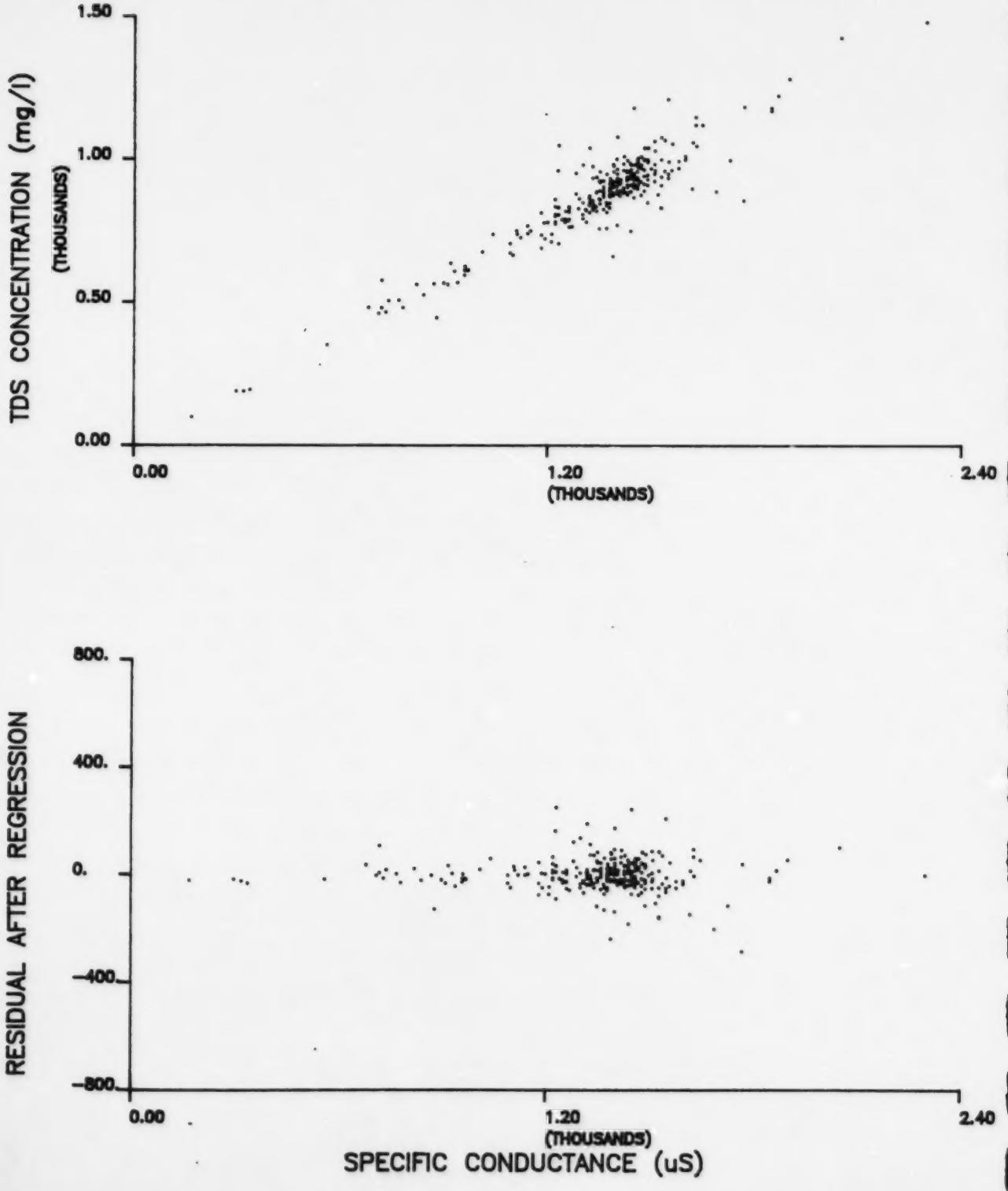

FIGURE 3.10
HydroQual

such as logarithmic or square root, which will tend to increase the uniformity of the data distribution about the regression line.

2) The change in residual variance may be illusory and associated with the frequency distribution of the data along the specific conductance axis. The variance of the constituents about the regression line may be as broad at low specific conductances as at high (the homoscedasticity assumption is therefore fulfilled). However, along any short section of the specific-conductance axis, the distribution of sample data about the regression line will tend to broaden as the number of data points along that section increases. This is because most points will tend to fall near the line, but as the sample size increases, more of the rare observations which are distant from the line will be detected. In the present cases, the majority of the data fall within a relatively narrow band of specific conductance between about 1200 and 1600 uS. This is also the area in which the distribution of residuals is broadest. This being the case, as sample sizes at the extremes of specific conductance increase, the distribution of residuals should become more uniform. If the constituent concentrations are truly distributed evenly along the regression line, a logarithm or square root transformation would be inappropriate since these would tend to decrease the precision of the intercept estimate.

Examination of residuals after regression can reveal a great deal about the structure of the data being examined and is a powerful tool when assessing whether the assumptions of regression have been fulfilled. We strongly recommend it become a standard part of future regression analyses.

3.4.2 Detecting Changes in Water Quality

When the above regression procedure was implemented it was felt

that any significant (presumably statistically significant) change in the regression coefficients caused by the addition of the most recently acquired data would signal a potential change in water quality which could then be investigated (Poplar River Bilaterlal Monitoring Committee, 1984). Comparing regression coefficients between successive years would be very insensitive at detecting such changes for two reasons:

1) If a change in the boron versus specific conductance or TDS versus specific-conductance relationships occurred in any given year, the previous data would tend to have a large influence upon the regression equation and the new data only a small effect. Consequently the equations would change but little and no statistical differences could be detected.

2) Even if a trend in the data existed, such that the regression coefficients tended to progressively increase or decrease as time passed, the gradual change in the regression coefficients (partially dampened by previous data) may not be statistically significant between successive years. This would be somewhat analogous to climbing a flight of steps, where the difference in height between any successive pair of runners may not be great (not statistically detectable), but one is still climbing.

If the objective of detecting changes in these relationships is to be pursued in future, more appropriate trend detecting statistical methodologies would have to be implemented.

3.4.3 Computation of Moving Averages with Regression Equations

STEP	OPERATION
1	With the regression equations (Table 3.3) each daily specific conductance reading is used to estimate a boron or TDS concentration (Table 3.4).

Table 3.4 Example of daily specific-conductance data from the observer at the International Boundary site along with TDS and BORON concentrations calculated using the equations obtained by regressing grab-sample TDS and boron data on grab-sample specific conductance:

TDS = 10.532942 + 0.639946*CONDUCTANCE
BORON = 0.268339 + 0.00145281*CONDUCTANCE

DATE	OBSERVER COND. (µS)	REGRESSION ESTIMATED TDS (mg l^{-1})	REGRESSION ESTIMATED BORON (mg l^{-1})	FLOW (cfs)	LOADINGS = PRODUCT OF FLOW TIMES BORON	LOADINGS = PRODUCT OF FLOW TIMES TDS
1 9 86	1390	900.057	1.751	2.4	4.2024	2160.136
2 9 86	1370	887.258	1.722	2.4	4.1328	2129.419
3 9 86	1390	900.057	1.751	2.8	4.9028	2520.159
4 9 86	1400	906.457	1.765	2.8	4.9420	2538.079
5 9 86	1380	893.658	1.736	2.7	4.6872	2412.876
6 9 86	1370	887.258	1.722	2.7	4.6494	2395.596
7 9 86	1340	868.06	1.678	2.6	4.3628	2256.956
8 9 86	1400	906.457	1.765	2.5	4.4125	2266.142
9 9 86	1430	925.655	1.809	2.7	4.8843	2499.268
10 9 86	1420	919.256	1.794	3.0	5.3820	2757.768
11 9 86	1380	893.658	1.736	3.0	5.2080	2680.974
12 9 86	1370	887.258	1.722	2.9	4.9938	2573.048
13 9 86	1380	893.658	1.736	2.6	4.5136	2323.510
14 9 86	1450	938.454	1.838	2.6	4.7788	2439.980
15 9 86	1450	938.454	1.838	2.6	4.7788	2439.980
16 9 86	1400	906.457	1.765	2.8	4.9420	2538.079
17 9 86	1400	906.457	1.765	2.8	4.9420	2538.079
18 9 86	1400	906.457	1.765	2.7	4.7655	2447.433
19 9 86	1400	906.457	1.765	2.9	5.1185	2628.725
20 9 86	1450	938.454	1.838	3.1	5.6978	2909.207
21 9 86	1490	964.052	1.896	3.5	6.6360	3374.182
22 9 86	1460	944.854	1.852	3.0	5.5560	2834.562
23 9 86	1440	932.055	1.823	2.8	5.1044	2609.754
24 9 86	1440	932.055	1.823	2.6	4.7398	2423.343
25 9 86	1430	925.655	1.809	4.0	7.2360	3702.620
26 9 86	1400	906.457	1.765	4.1	7.2365	3716.473
27 9 86	1380	893.658	1.736	3.5	6.0760	3127.803
28 9 86	1380	893.658	1.736	3.1	5.3816	2770.339
29 9 86	1380	893.658	1.736	2.8	4.8608	2502.242
30 9 86	1460	944.854	1.852	2.7	5.0004	2551.105
TOTALS		27340.890	53.289	86.71	54.1245	79067.840

Table 3.5 Flow weighted monthly mean concentratins of TDS and boron based upon daily specific-conductance readings,and their three-month flow-weighted moving averages.

DATE	FLOW-WEIGHTED MONTHLY MEAN BORON (mg l^{-1})	FLOW-WEIGHTED MONTHLY MEAN TDS (mg l^{-1})	MONTHLY TOTAL FLOW (cfs)	THREE-MONTH FLOW-WEIGHTED MOVING AVERAGE BORON (mg l^{-1})	THREE-MONTH FLOW-WEIGHTED MOVING AVERAGE TDS (mg l^{-1})
15-JAN-86	1.81	927	90.40		
15-FEB-86	1.71	882	155.10	1.46	774
15-MAR-86	1.44	761	2478.00	1.46	772
15-APR-86	1.58	827	202.30	1.47	775
15-MAY-86	1.63	846	322.60	1.62	844
15-JUN-86	1.69	873	105.70	1.67	863
15-JUL-86	1.78	912	95.70	1.75	898
15-AUG-86	1.78	915	79.20	1.78	913
15-SEP-86	1.78	912	86.70		

2 Loadings are calculated by taking the product of flow and each constituent concentration.

3 Within each month, and for each constituent, the loadings and flows are summed.

4 The flow-weighted monthly averages (Table 3.5) are computed by dividing the sum of constituent loadings by the flow total

e.g.

$$\text{Boron} \quad \frac{154.1245}{86.7} = 1.78$$

$$\text{TDS} \quad \frac{79067.840}{86.7} = 912$$

Three-month flow-weighted moving averages (Table 3.5, Figures 3.11 and 3.12) are then calculated as per Section 3.4.

3.5 Alternative Regression Relationships

There are three alternatives available for the way in which the regression relationship predicting boron and TDS concentrations from specific conductance could be derived.

1. Regress boron and TDS on specific conductance from the data obtained from the periodic grab samples. This relationship can then be used to predict boron and TDS using the daily readings obtained by the observer at the International Boundary station. This is the procedure which has been followed to date, and will be the base case against which the results of the following analyses will be compared.

2. The periodic grab samples were analyzed in different laboratories (the USGS Lab in Denver and Environment Canada labs in Calgary, Saskatoon and Burlington) and there may be

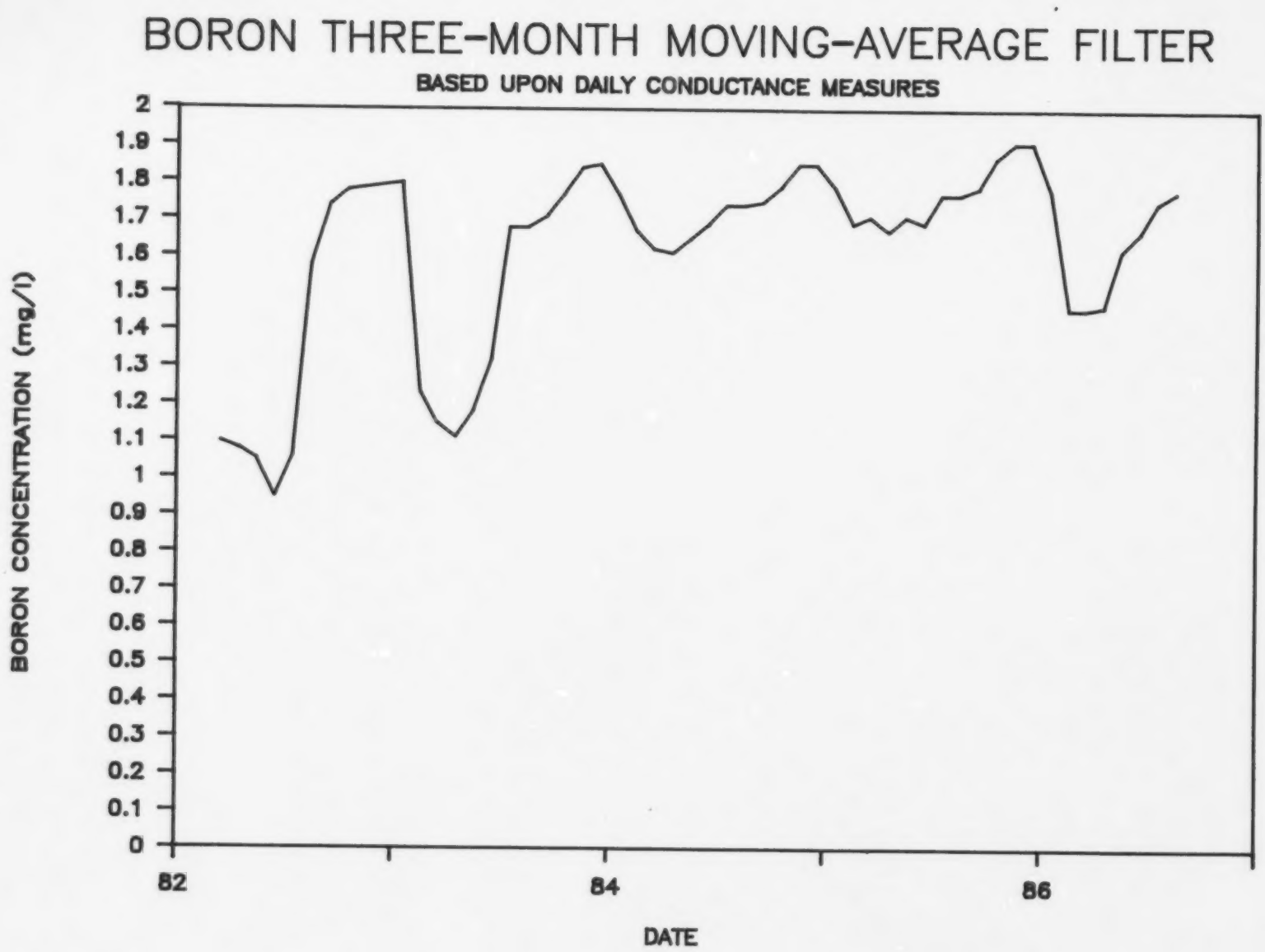

FIGURE 3.11
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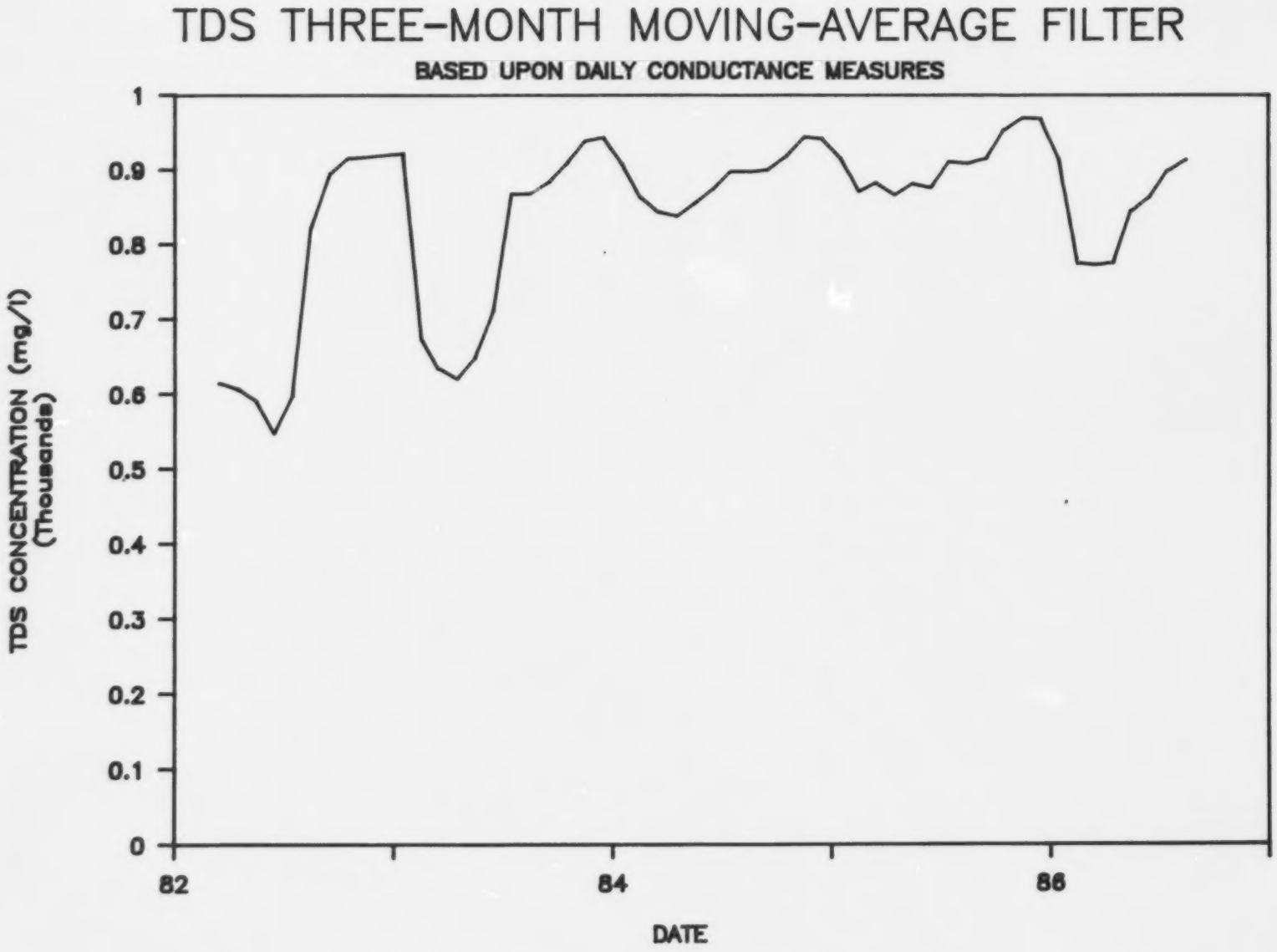

FIGURE 3.12
HydroQual

some bias between their results. However, the samples collected by the observer at the International Boundary are all analyzed in Denver. If there is bias between the laboratories it would also be reflected in the resulting regression equations, and passed on to the regression estimates of daily boron and TDS concentration since specific conductance from only the Denver laboratory are used to predict these values. (It should also be noted that twelve specific-conductance readings supplied by Saskatchewan Power Corporation were also included in the data used to estimate the regression equations.)

If bias exists it could be eliminated from the daily estimates by obtaining a relationship between the observer's daily specific-conductance reading and the grab-sample conductance reading. Using this relationship the observer's specific-conductance values could be adjusted into line with those used to generate the equations. These adjusted specific-conductance values would then be used as input to the regression equations relating boron and TDS to specific conductance.

3. Method two is somewhat circuitous since it involves two steps. A more direct approach would be to regress the grab sample boron and TDS data directly on the observer specific-conductance data and use this relationship to predict daily boron and TDS concentrations.

We undertook both the two-step procedure and the direct method of estimation and compared them to the procedures which have been used to date (referred to here as the base case).

3.5.1 Detection of Bias

Analysis of covariance was undertaken to test for bias between the USGS, DOE and SPC specific-conductance data as estimators of boron and TDS (Table 3.6).

The slopes of the regression relationships for the three specific-conductance sources were not significantly different, but there was significant additive bias. Relative to the Canadian data the USGS data significantly underestimate boron by 0.058 mg l^{-1} and overestimate TDS by 27.093 mg l^{-1}. The SPC data overestimate boron by 0.144 mg l^{-1} and TDS by 92.382 mg l^{-1} relative to the Canadian data.

Data for grab sample specific-conductances were regressed upon the specific-conductance estimates from the observer taken on the same day, and significant additive and proportional biases were detected. The resulting equation was:

$$COND_{grab} = -119.515 + 1.084 * COND_{observer} \qquad (3.2)$$

Using this relationship the observer specific-conductance values were transformed into estimates of the grab sample specific conductances. These derived values were then used to predict boron and TDS concentrations using the base-case regression equations (Table 3.6). The resulting values were then subtracted from the base-case estimates and the differences plotted against time (Figures 3.13 and 3.14). Positive differences occurred when the base-case estimates were higher. The majority of the differences are positive, but small. The maximum difference for boron was about 0.095 mg l^{-1}, and for TDS about 42 mg l^{-1}.

Therefore, although bias was shown to exist between the observer's specific-conductance estimates and those for the grab samples, it has but a minor effect upon the daily concentration estimates.

Table 3.6 Analyses of covariance to detect bias between U.S.G.S., D.O.E., and S.P.C. data as predictors of boron and TDS. Simple regressions of conductance (all sources pooled) versus boron and TDS (the base-case equations) have also been included for comparative purposes. All coefficients are significantly different form zero at the alpha=0.05 level of significance.

DEPENDENT VARIABLE: BORON
N: 292
SQUARED MULTIPLE r: .746

VARIABLE	COEFFICIENT	STD ERROR	t	TWO-TAILED PROBABILITY
CONSTANT	-0.287	0.070	-4.076	0.000
USGS	-0.058	0.026	-2.244	0.026
SPC	0.144	0.059	2.445	0.015
COND	0.001481	0.510	29.024	0.000

DEPENDENT VARIABLE: BORON
N: 292
SQUARED MULTIPLE r: .733

VARIABLE	COEFFICIENT	STD ERROR	t	TWO-TAILED PROBABILITY
CONSTANT	-0.268	0.070	-3.826	0.000
COND	0.0014527	0.514	28.241	0.000

DEPENDENT VARIABLE: BORON
N: 292
SQUARED MULTIPLE r: .888

VARIABLE	COEFFICIENT	STD ERROR	t	TWO-TAILED PROBABILITY
CONSTANT	-15.697	18.875	-0.832	0.406
USGS	27.093	6.959	3.893	0.000
SPC	92.382	15.805	5.845	0.000
COND	0.6467031	136.897	47.240	0.000

DEPENDENT VARIABLE: BORON
N: 292
SQUARED MULTIPLE r: .872

VARIABLE	COEFFICIENT	STD ERROR	t	TWO-TAILED PROBABILITY
CONSTANT	10.526	19.655	0.536	0.593
COND	0.6399514	144.247	44.365	0.000

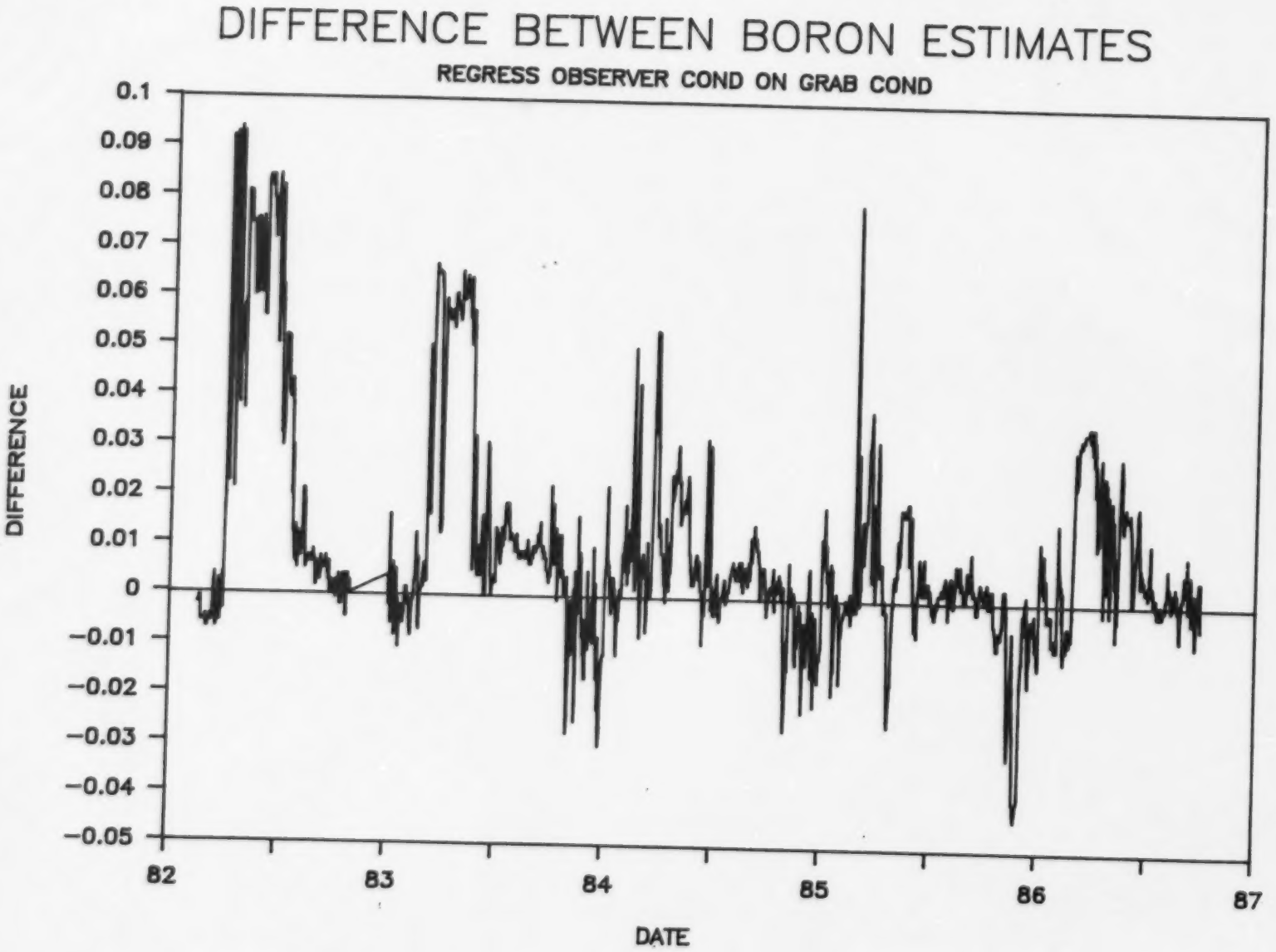

FIGURE 3.13
HydroQual

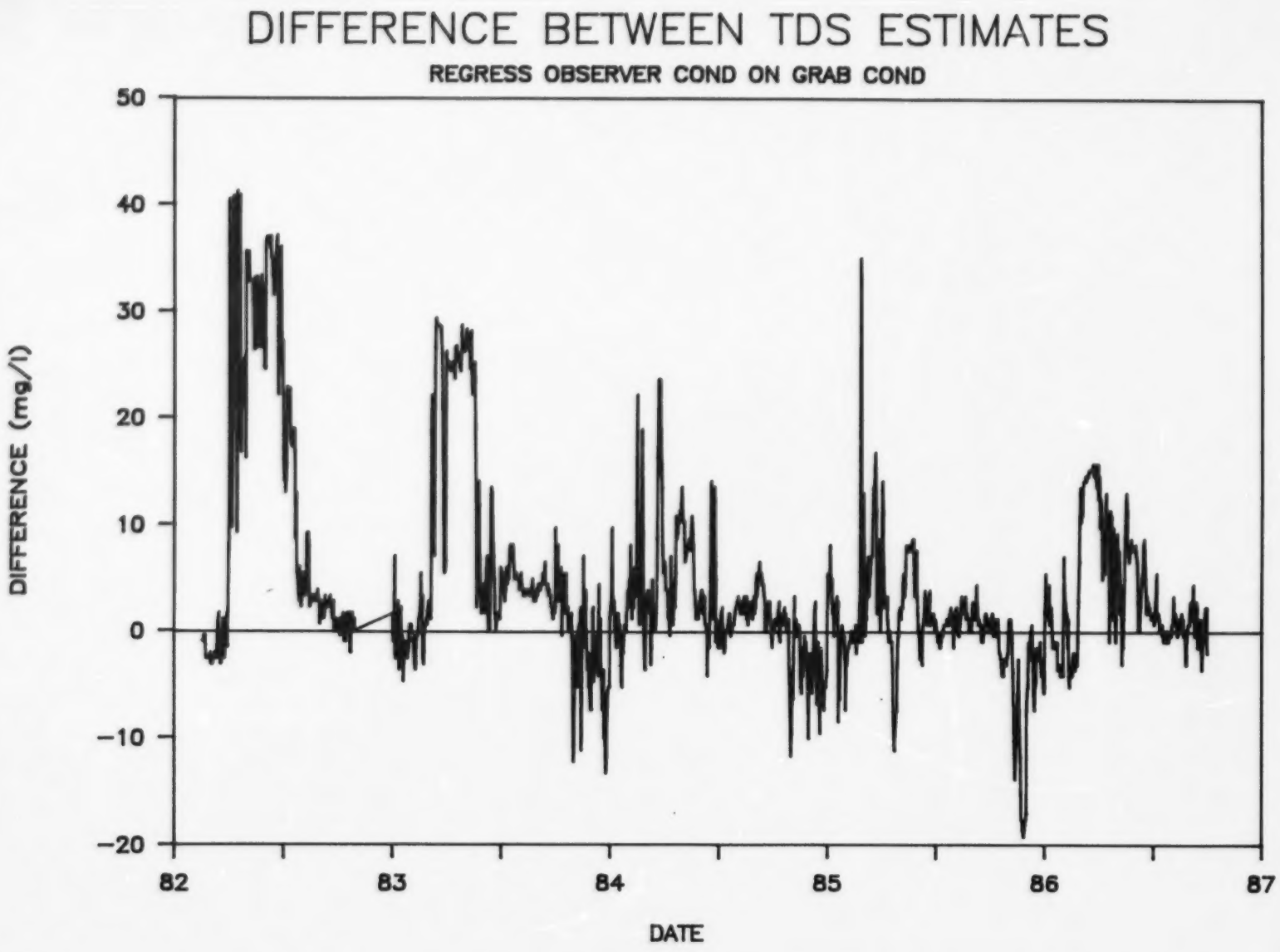

FIGURE 3.14
HydroQual

3.5.2 Using Observer Data Directly

In the last section we demonstrated a bias between observer and grab-sample specific-conductance estimates. Here we eliminate the grab-sample specific-conductance estimates from the analysis and regress the grab-sample boron and TDS concentrations directly on the observer's specific-conductance data. The resulting equations are:

$$BORON = -0.466 + 0.0015471 * COND_{observer} \quad (3.3)$$

and

$$TDS = -92.839 + 0.7133813 * COND_{observer} \quad (3.4)$$

Comparing these to the equations used in the base case (Table 3.6) it is apparent that the major differences between coefficients are associated with the intercept terms (-0.466 and -0.268 for boron and -92.839 and 10.526 for TDS). These biases are not surprising considering the additive biases detected between labs (Table 3.6).

Equations 3.3 and 3.4 were used to predict daily boron and TDS concentrations directly from the observer's specific-conductance data and the results were subtracted from the base-case estimates (Figures 3.15 and 3.16). In this case the differences were larger than those obtained in the previous section, but again were not particularly large within the context of the IJC's objectives.

3.5.3 Conclusions

Although the regression equations used to date appear to be somewhat biased, the corrections obtained by alternative estimation techniques are not profound. We recommend that in future the regression equations used to estimate daily boron and TDS concentrations be derived based upon the observer's specific-

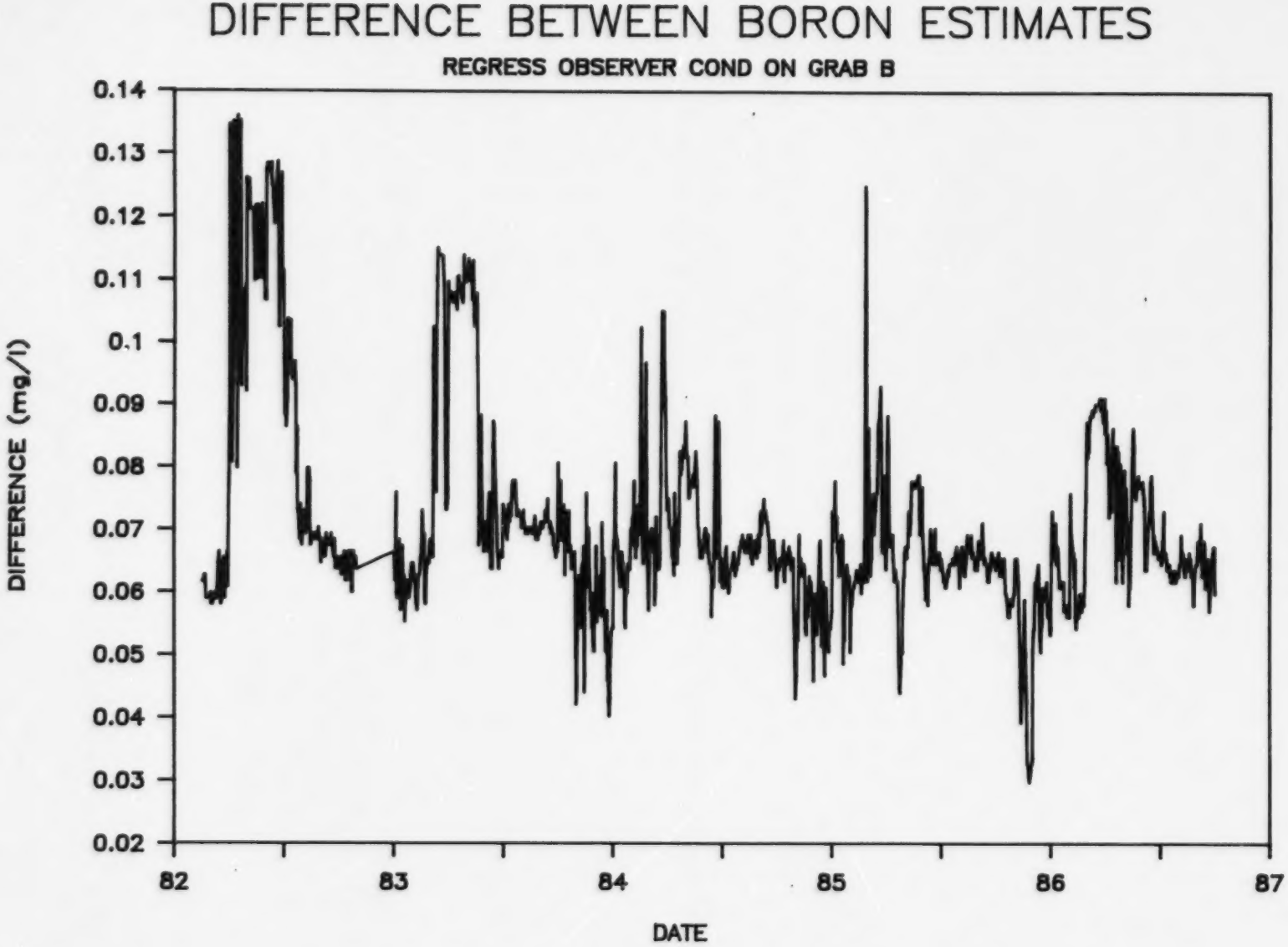

FIGURE 3.15
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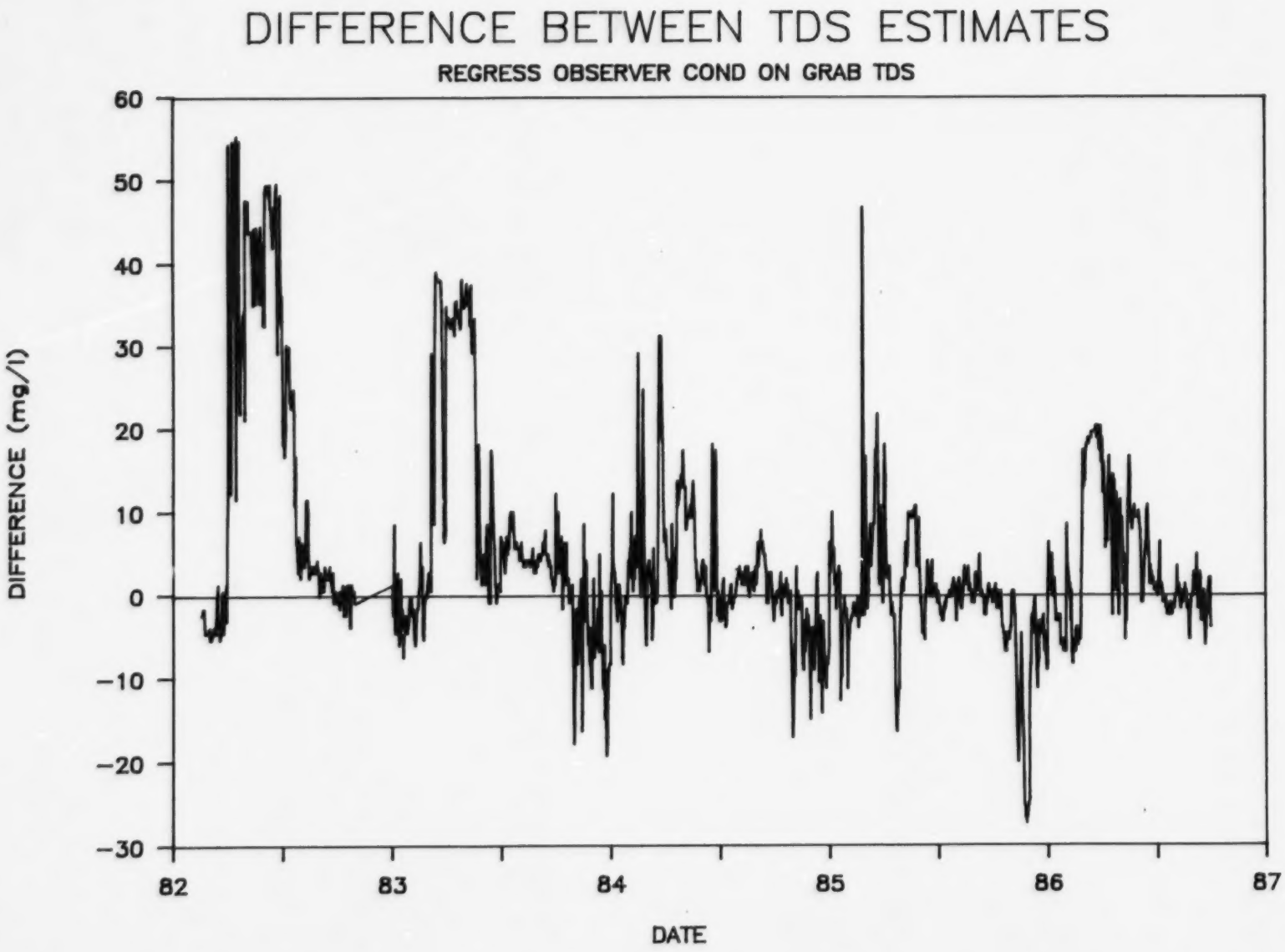

FIGURE 3.16
HydroQual

conductance estimates rather than those from the grab samples since this is the most direct method of eliminating the bias.

3.6 Moving-Average Filters

The IJC recommended that three-month and five-year flow-weighted moving averages be computed for assessment of compliance with the objectives. Moving averages however tend to act as frequency by-pass filters and this characteristic should be appreciated when interpreting their output. Cyclic phenomena with a wave length exactly equal to the length of the moving average are completely filtered out (Figure 3.17). This is because for every point which lies above the mean there is another point lying an equal distance below the mean and the two deviations cancel, and therefore move the mean neither up nor down. The same holds true for all harmonics of this fundamental frequency. Frequencies which are longer than the range of the filter, or which are not harmonics of the fundamental frequency are passed through it to a greater or lesser extent.

In the present context seasonal cycles may exist in the boron and TDS concentrations. If so, they may be obscured by a moving average, despite the fact that the amplitudes of the cycles may be very large. For instance, it is not unlikely that annual cycles exist. If they do, they would be completely obscured by the five-year moving average since exactly five annual cycles fall within the range of the five year moving average (1 year cycles are harmonics of a five year fundamental).

To demonstrate the filtering effect of moving averages we applied five filters with different ranges to the boron data. Both simple concentrations and flow-weighted concentrations were considered, and the value of the moving average was plotted at the end of its range rather than in its centre as is done in the base case (Figures 3.16 to 3.19). The 30-day and 60-day moving averages

EXAMPLE OF CYCLIC PATTERN BEING REMOVED BY MOVING-AVERAGE FILTER

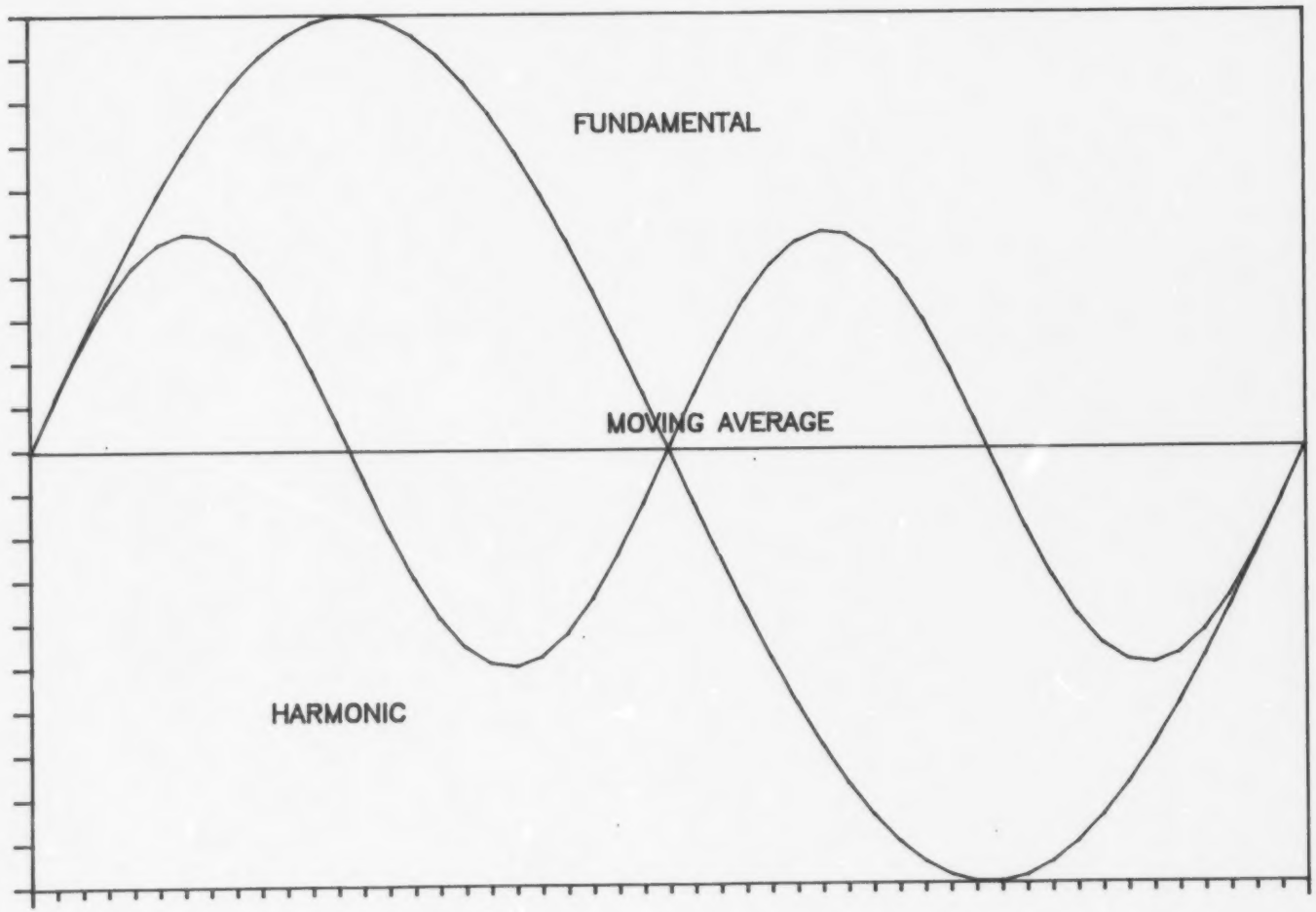

FIGURE 3.17
HydroQual

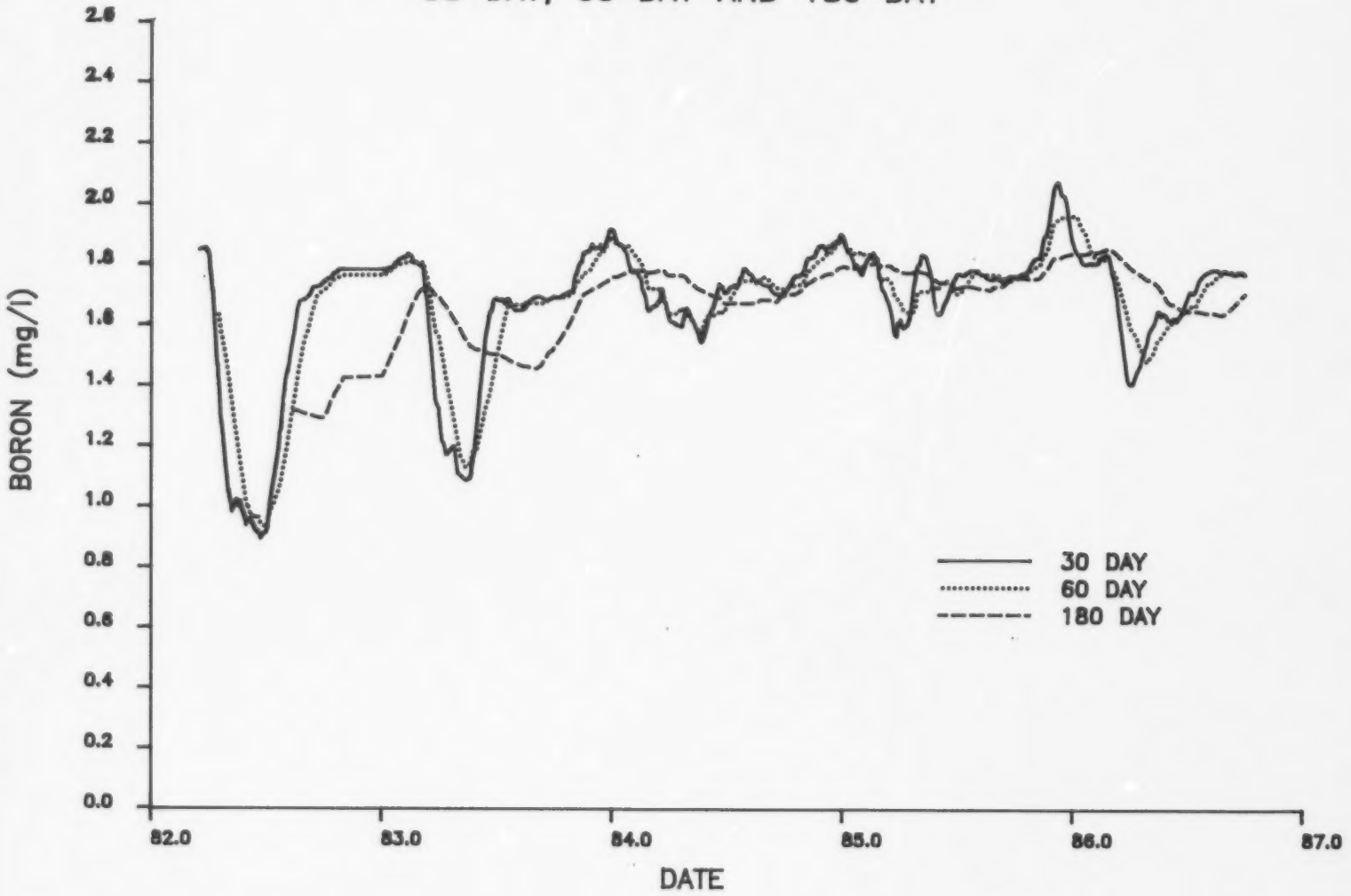

FIGURE 3.18
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BORON – FLOW WEIGHTED MOVING-AVERAGE FILTERS

30-DAY, 60-DAY AND 180-DAY

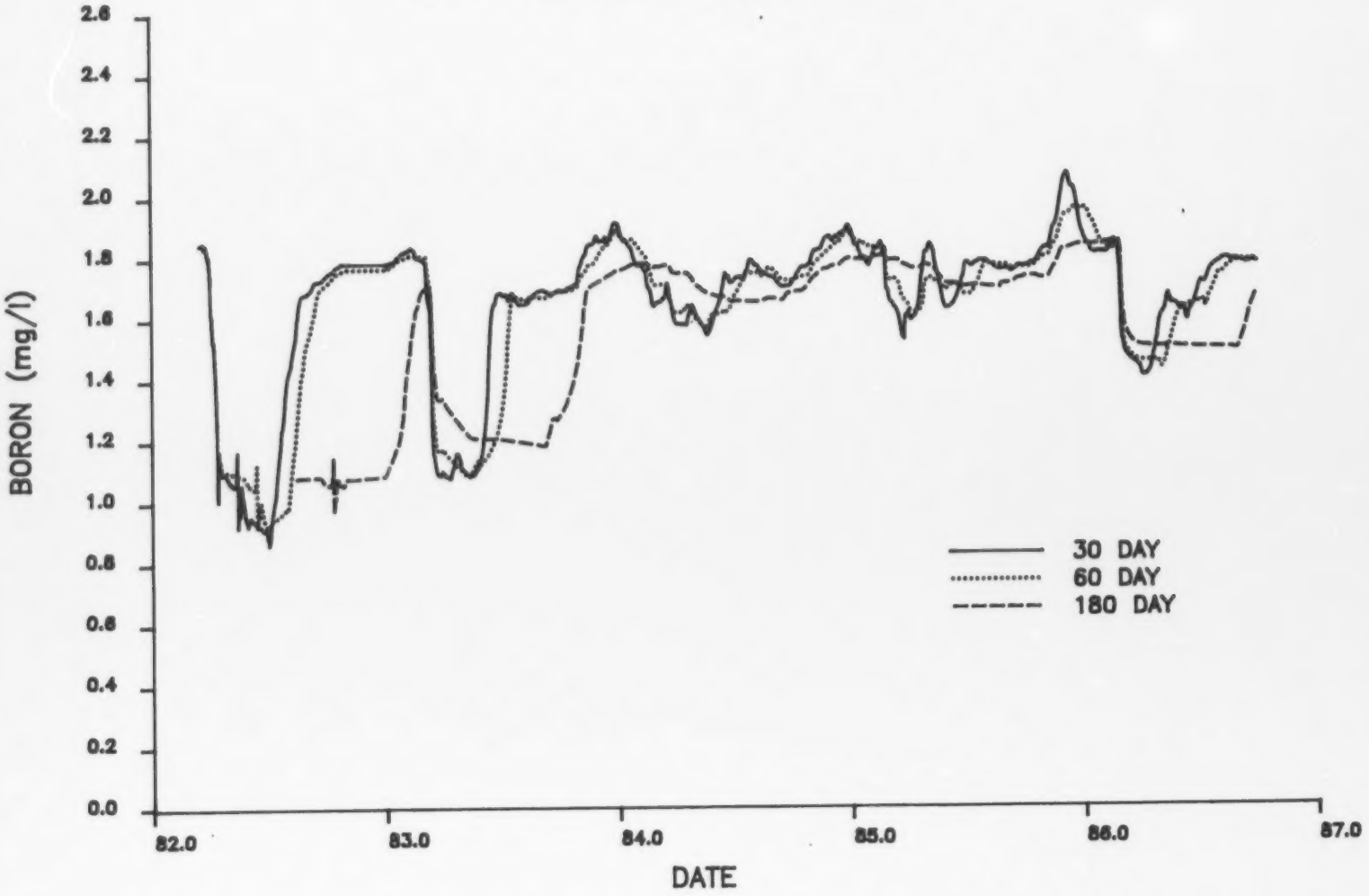

FIGURE 3.19
HydroQual

follow one another almost identically (Figures 3.18 and 3.19), while the 180-day filters show some smoothing. However, there is still considerable variation through time. The one-year and two-year filters have largely obscured within-year seasonal cycles (Figures 3.20 and 3.21).

Comparing Figure 3.18 with 3.19, it is also worth noting that the 30-day, 60-day and 180-day moving averages for flow-weighted concentrations and simple concentrations are almost identical. However, the flow-weighted averages tend to show some jitters that are not present for the simple concentration data. For instance, in Figure 3.19 there are a series of spikes on the bottom of the troughs which occur in 1982 and 1983, but these are not visible in the corresponding periods in Figure 3.18.

On the other hand, the flow effects upon the one-year and two-year moving averages were considerable (Figures 3.20 and 3.21). The averages for the simple concentrations are quite stable through time (Figure 3.21), while the flow-weighted averages show erratic behavior, shifting up and down in response to various flow events. Indeed, comparing Figure 3.20 with Figure 3.22 reveals that the flow-weighted moving average for boron is virtually a perfect inverse of the moving averages for flow. This reflects the profound influence of the sum of the flows in the denominator of the flow weighting equation (e.g. Equation 3.1). It thus appears that the changes in the long-term flow-weighted moving average concentrations primarily reflect the behaviour of flows within the system rather than constituent concentrations.

3.7 Effects of Rare Flow Events

Figures 3.7 and 3.8 indicate that a 20% drop in the five-year flow-weighted moving averages occurs in mid-April, 1979. This reflects the major flood event that occurred on April 15 and 16, 1982 (Figure 3.2). Although not represented in Figures 3.7 and 3.8,

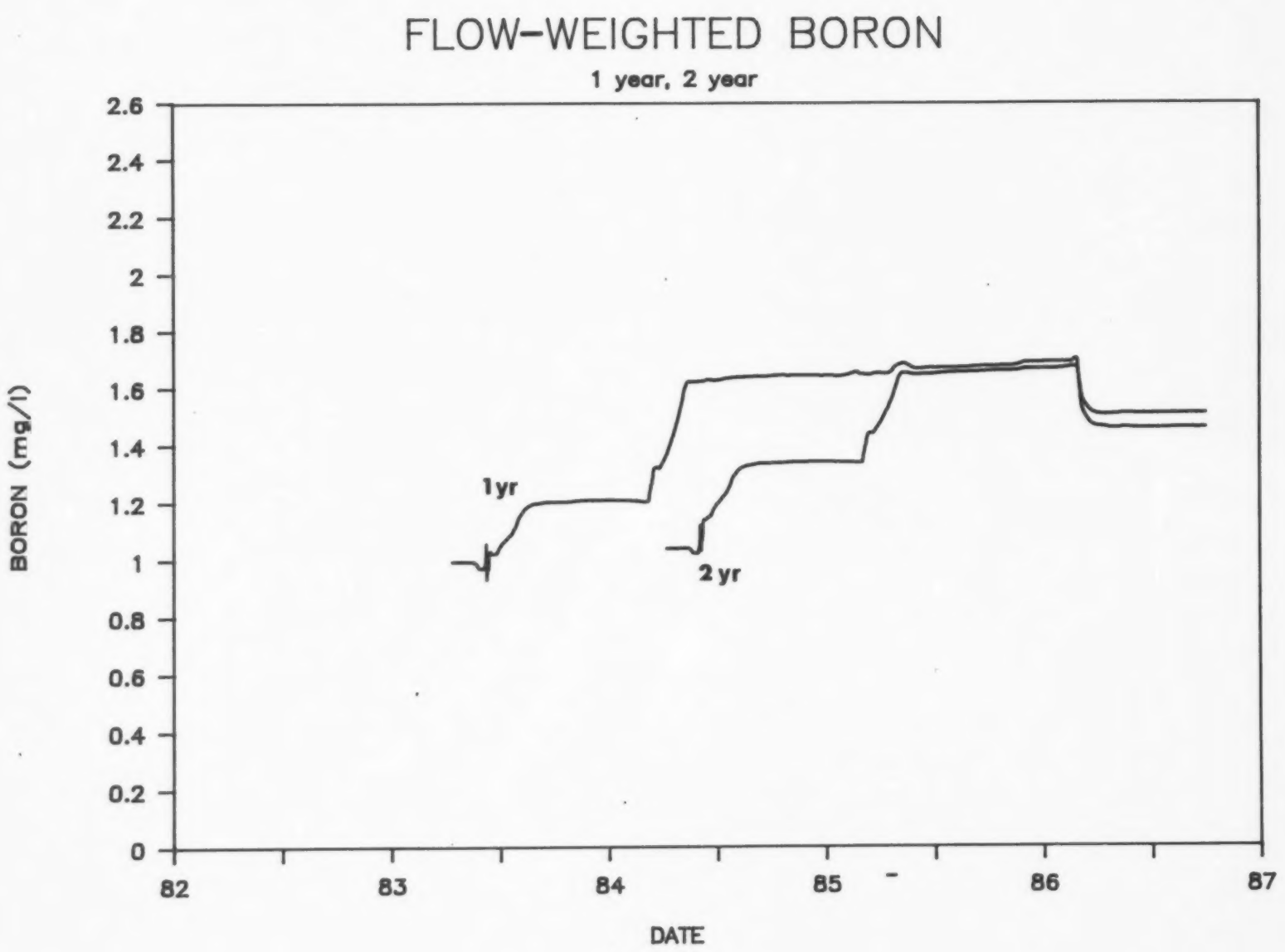

FIGURE 3.20
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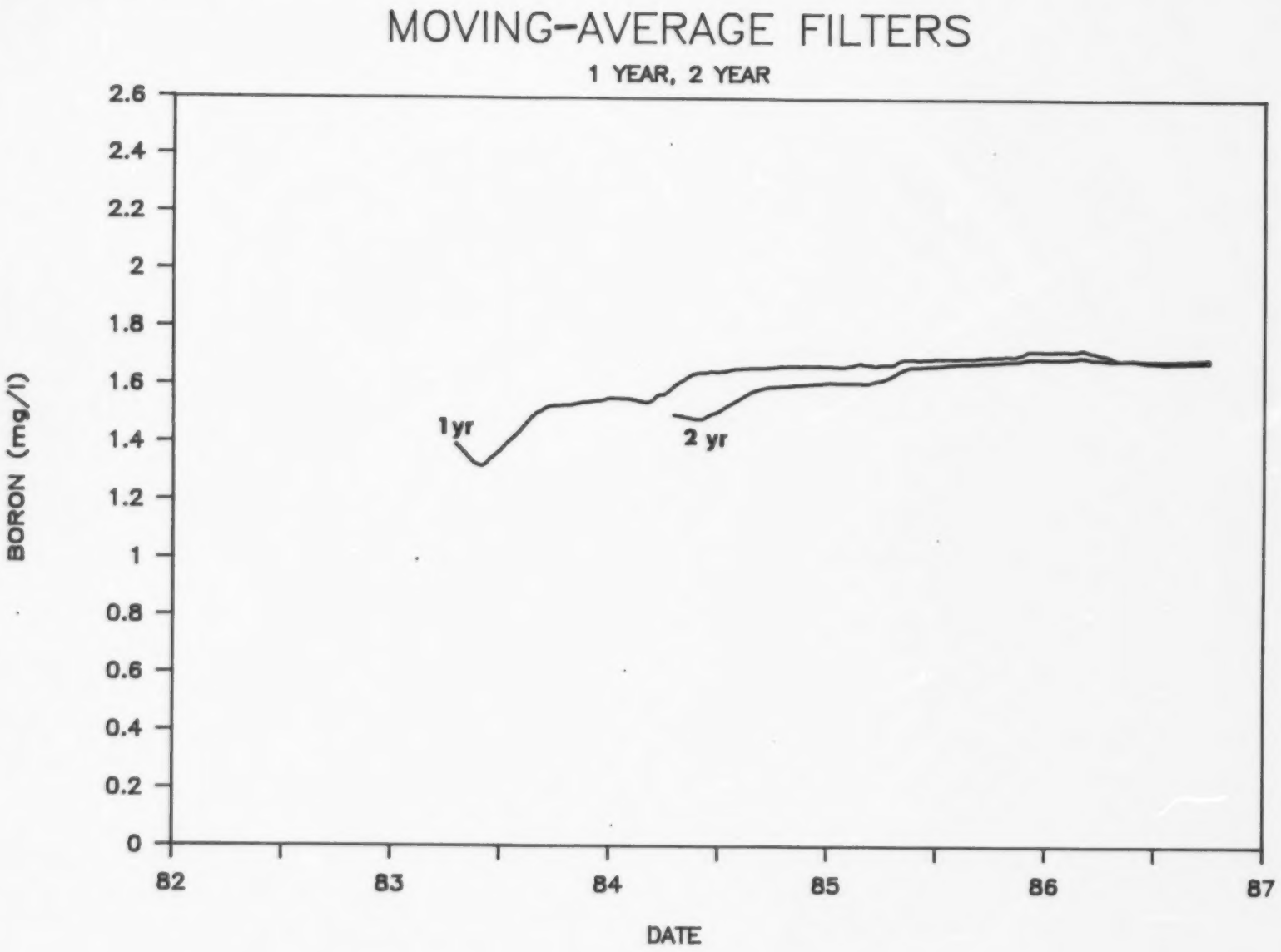

FIGURE 3.21
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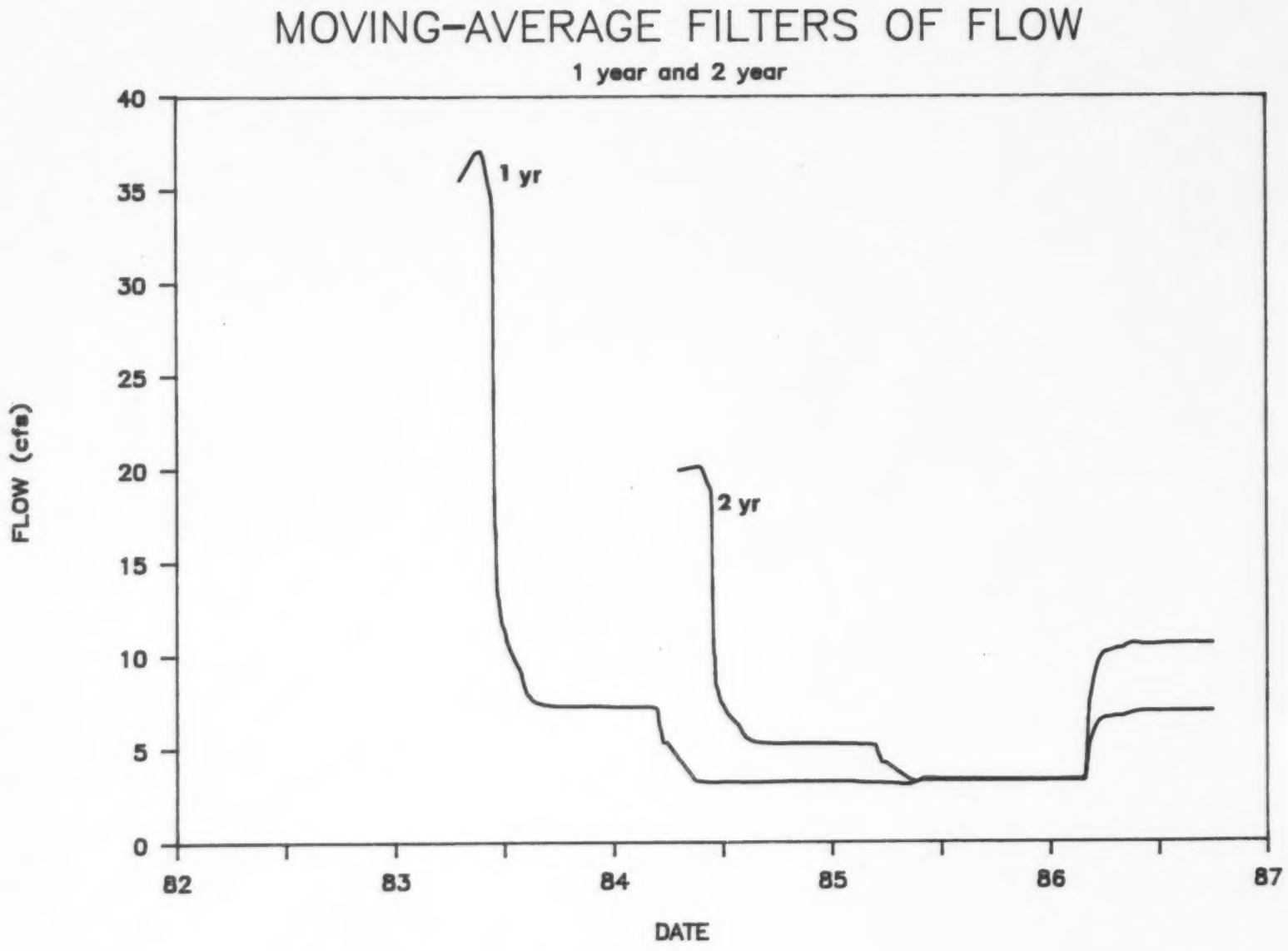

FIGURE 3.22
HydroQual

when the moving average includes the April 19, 1987 data, the plots of the moving average show a recovery in April 1979, a full five years after the initial drop (W. Gummer, personal communication). This reflects the left end of the filter moving past the 1982 flood event, so it no longer influences the moving average.

It seems undesirable that an entire five-year sequence of moving averages should be so profoundly influenced by a single flow event of such short duration. The distribution of recorded flows (Figure 3.23) shows a large difference between the two high April 1982 flows (2080 and 2930 cfs) and the next highest flow (241 cfs). Three different methods for reducing the impact of infrequent flow events on the five-year flow-weighted moving averages were investigated:

- Data for days with flows > 1000 cfs were dropped (Figures3.24 and 3.25)
- Data for days with flows > 100 cfs were dropped (Figures 3.26 and 3.27)
- Monthly mean flows used for flow weighting were geometric means (Figures 3.28 and 3.29).

Note that in Figures 3.24 to 3.29 the moving averages are shifted 2.5 years to the right of the corresponding averages in Figures 3.7 and 3.8. This is due to plotting the moving average at the date corresponding to its end (most recent) date rather than its midpoint. The advantage of this approach is that any change in the moving average is plotted on the same date as the event occurred which caused the change. Therefore, the user of the plot does not have to mentally shift events from one time frame to another when using the plots. We recommend this practice be used in future.

All of the methods for eliminating the impact of rare, high-flow events seem to have been about equally effective since the large drop due to the 1982 flood is no longer evident. The first two methods, dropping data associated with high flow days, is somewhat

Figure 3.23 Stem and leaf plot of the daily mean flows at the International Boarder, East Fork of the Poplar River.

```
N          =          292
MINIMUM IS:           0.330
MAXIMUN IS:        2930.000
    0    3
    0    5566677789999
    1    003
    1    555677888888888999999
    2 H  000011111111122222223334444444444444
    2    555555555566666666666666667777777777888888888888889999999
    3 M  000000000000000011111111111122222222233333333333344
    3    55556677788889
    4    000011111122244
    4 H  56667777799
    5    012
    5    89
    6    3
    7    1114
    7    68
    8    24558
    9    1289
   12    0
   13    0
   15    0
   18    0
   19    000
   24    0000000000
   25    0
   27    00
   30    0
   31    0
   32    0
   35    0
   40    00
   41    0
   53    00
   60    00
   65    0
   75    0
   87    0
  100    0
  119    0
  138    0
  155    0
  173    0
  185    0
  198    0
  205    0
  238    0
  241    0
 2080    0
 2930    0
```

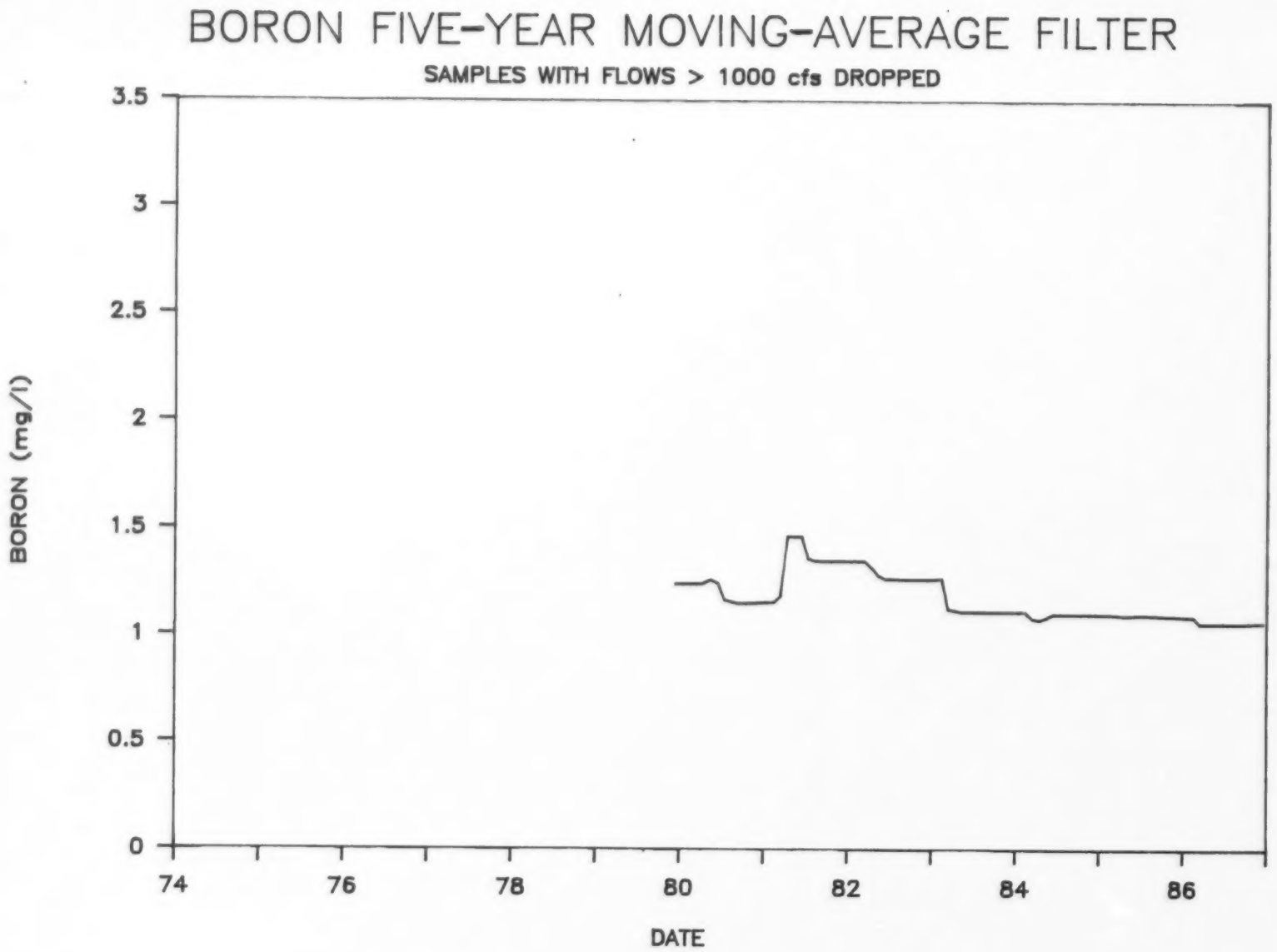

FIGURE 3.24
HydroQual

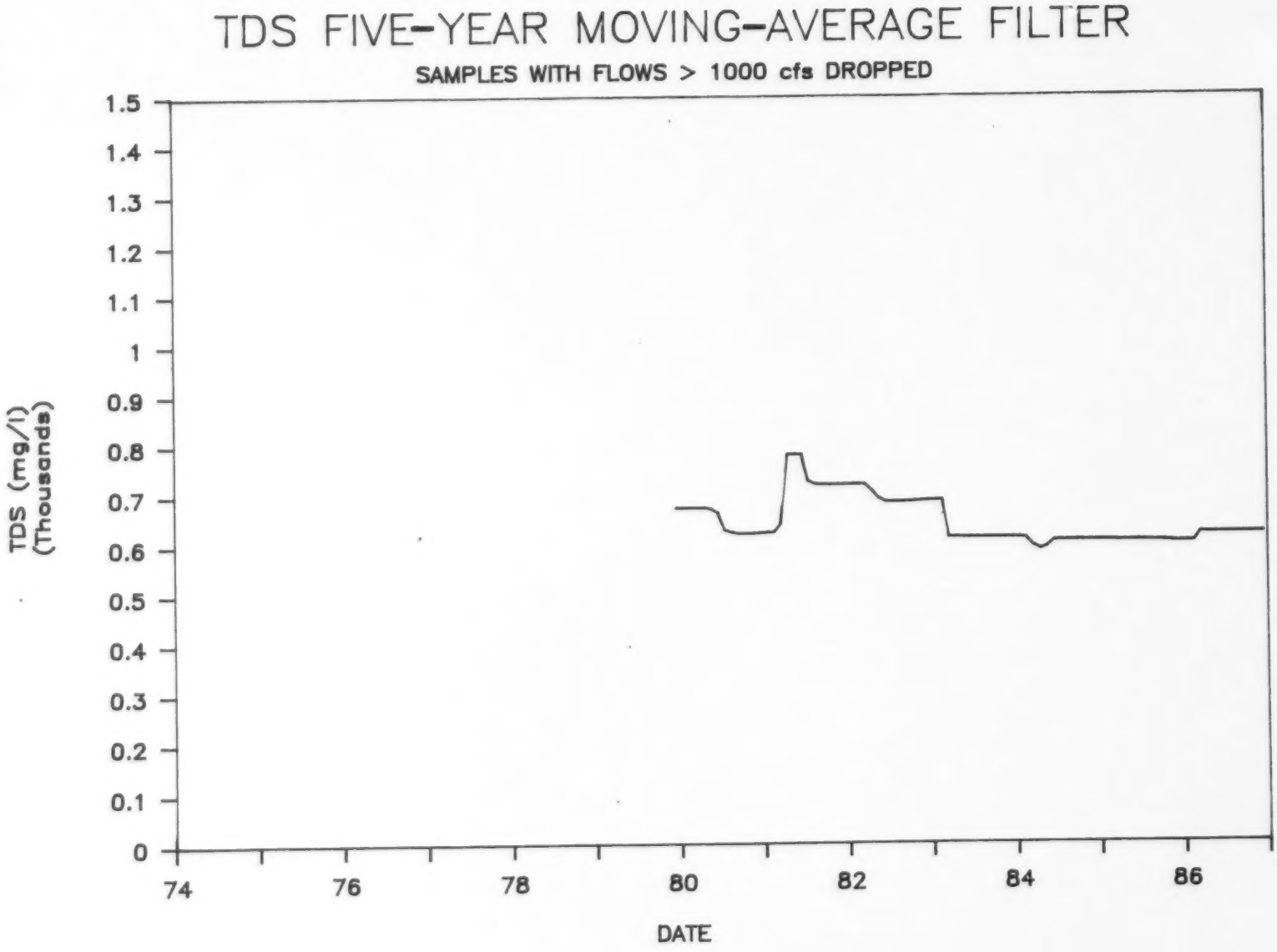

FIGURE 3 25
HydroQual

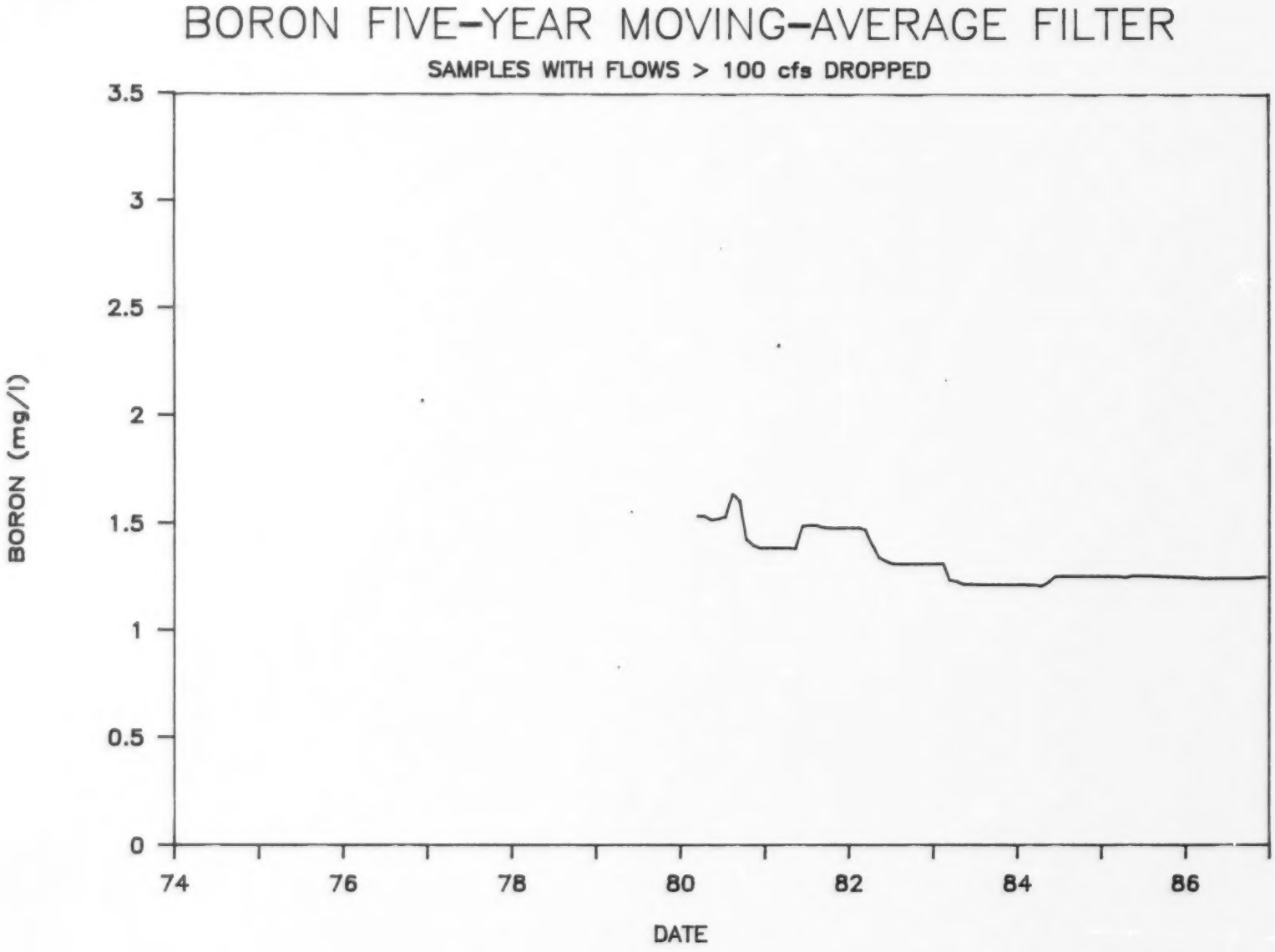

FIGURE 3.26
HydroQual

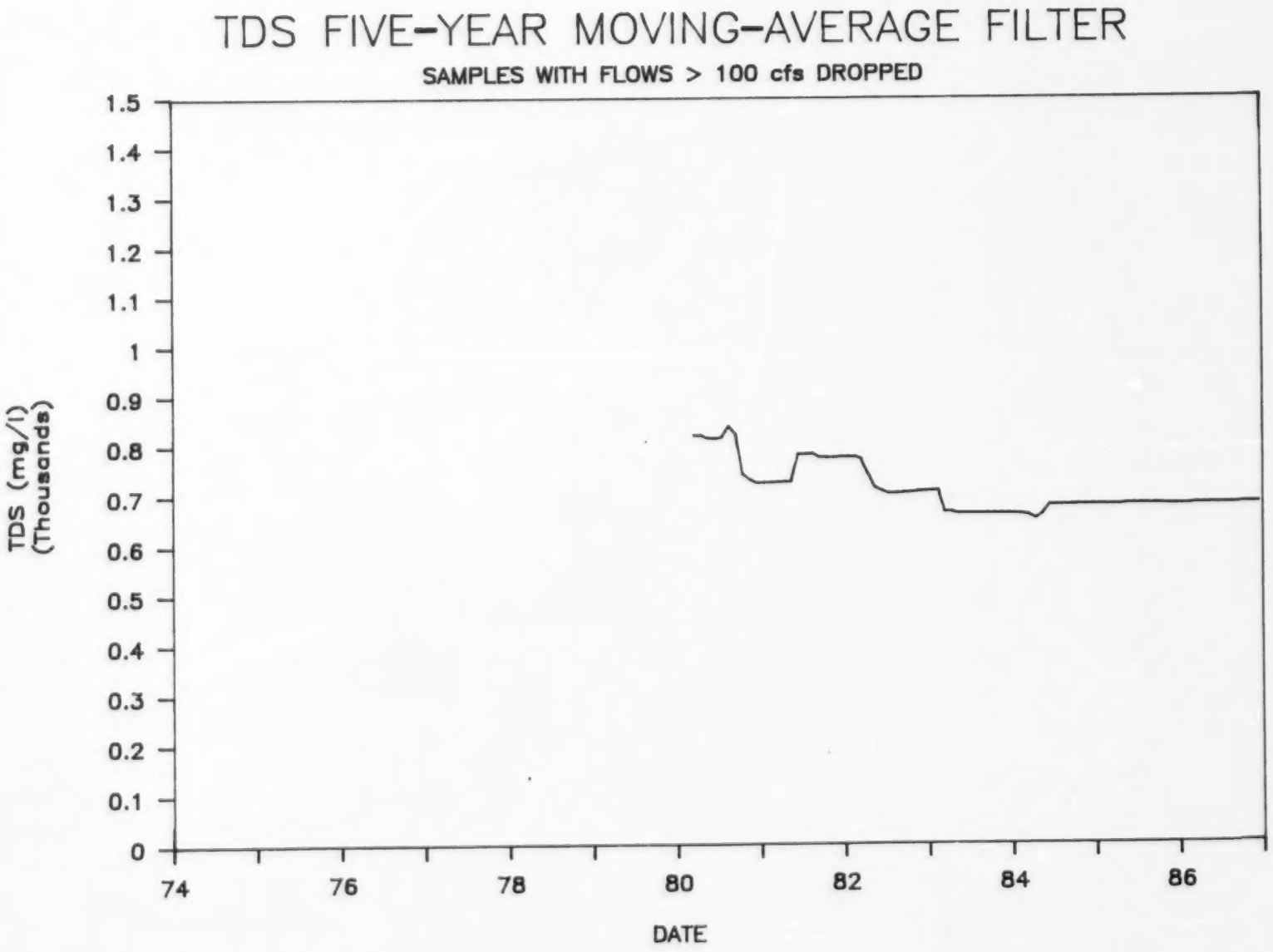

FIGURE 3 27
HydroQual

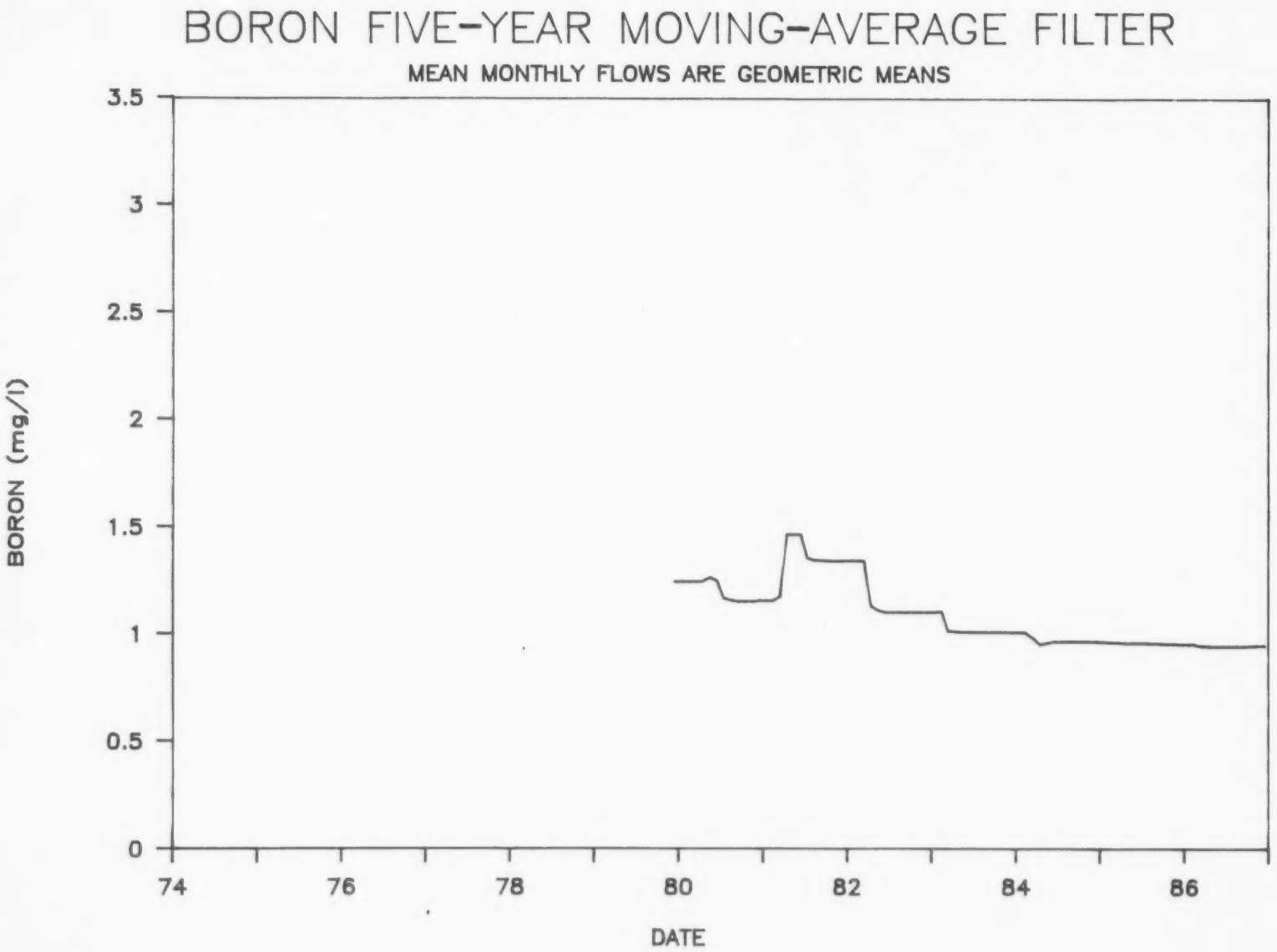

FIGURE 3.28
HydroQual

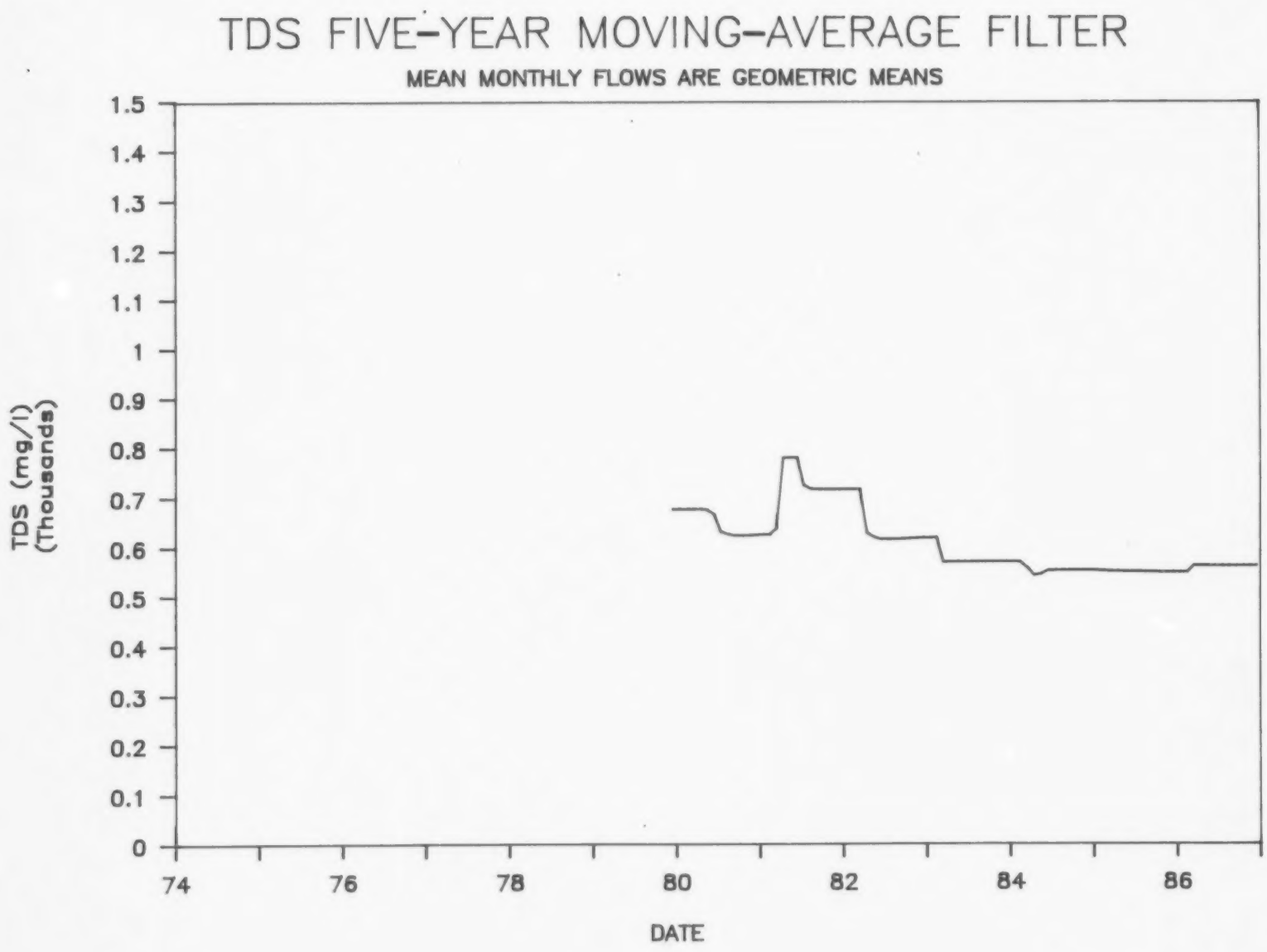

FIGURE 3.29
HydroQual

arbitrary with respect to choosing the cutoff above which data are to be dropped. This is an important consideration since the more high-flow data which are eliminated, the lower the flow-weighted moving average.It seems that the method of using geometric means as the monthly mean flow is most appropriate since it uses all the data, and therefore allows all data to influence the moving average. If high flow events become usual in this system their influence upon the geometric mean would become proportionally large and the flow-weighted averages would more accurately represent the state of the system.

3.8 Relevance to Irrigation

The IJC set the boron and TDS objectives based upon their suspected toxicity to barley and alfalfa, respectively. There were a few hectares of these crops along the East Fork and lower reaches of the Poplar River which were irrigated with river water. For instance, in 1975 there were 18 ha of barley irrigated just south of Scobey, Montana. Irrigated acreages were expected to rise by the year 2000.

The toxicity data that were reviewed by the IJC were very difficult to interpret and frequently contained contradictory information. For the agricultural crops grown in the area, the data seemed to suggest that: 1) barley was the most sensitive to boron, 2) alfalfa was the most sensitive to TDS. These same data further suggested that the levels at which these constituents become toxic are very sensitive to a variety of local soil factors such as porosity and pH, as well as climatic variables. Lacking concise data upon which to base the objectives, the IJC chose values that they judged to be reasonable, but which were only to be used as interim values. The commission requested that site-specific research be undertaken to determine the sensitivity of crops in the area and that their interim objectives be reviewed in light of the findings of this research. This research does not appear to have

been undertaken.

We have reviewed the distributions of daily boron and TDS concentration (as predicted from the regression equations) during the March to October period covered by the IJC's proposed objectives, and they can be summarized as follows:

	March to October		May 14 to August 30	
	TDS	Boron	TDS	Boron
Number of cases	1252	1252	545	545
Minimum (mg l^{-1})	429	0.68	478	0.79
Maximum (mg l^{-1})	1066	2.13	970	1.91
Mean (mg l^{-1})	843	1.62	844	1.63
Standard Deviation (mg l^{-1})	116	0.26	79	0.18

Only rarely during the period covered by the objectives did the boron concentration exceed 2.0 mg l^{-1}, and it was always well below the 2.5 mg l^{-1} maximum required by the objectives. TDS behaved similarly and was also far from the limits set by the objectives.

The period during which water is generally most intensively used for irrigation is from early June to late July for barley, and mid-May to mid- to possibly late August for alfalfa. The distribution of the data during this more important period shows both boron and TDS concentrations to be even further from potentially toxic levels. These results suggest that extensive and sophisticated analyses of the data may not have to be considered since individual daily concentrations never exceed the levels set by the objectives, nor will any of the running averages. It is only when frequent exceedances occur that the running averages would be useful in assessing the potential impact on the crops.

3.9 Appropriateness of Flow-weighting the Objectives

We submit that the flow-weighting requirement of the boron and TDS

objectives is inappropriate for the objective of protecting irrigated crops.

To appreciate our reasoning, consider a stream of water of varying flow, and with a varying concentration of some dissolved material in it, which is being captured in a single, fully mixed impoundment. The concentration of the material in the impoundment is properly calculated as the flow-weighted average concentration of the stream entering the impoundment.

One can consider the field onto which irrigation water is applied as an impoundment. The irrigator's concern is that the concentration of some potential toxicant does not exceed toxic levels on this field. If the flow rate of the irrigation input to the field was known, as was the toxicant concentration one would calculate the concentration on the field as the flow-weighted average calculated from irrigation flow rate and the concentration in the irrigation water. This calculation is **independent** of the flow in the river from which the irrigation water is being drawn. That is to say, it is irrelevant how quickly or how much river water is rushing past the intake structure (river flows), but it is important what the concentration of the toxicant in the irrigation water might be and the rate at which it is applied.

If there was a strong positive correlation between river flows and the rate of irrigation withdrawal, then the errors associated with (river) flow-weighted averaging would be less severe. Under the apportionment agreement, water is released from Cookson Reservoir on request from U.S. authorities, and these releases tend to coincide with irrigation withdrawals. This operating regime thus tends to cause a positive correlation between river flows and total irrigation withdrawals. However, for any given field (which is the scale at which toxicant dosing must be considered) the correlation would still be rather weak. Each irrigator will tend to withdraw water from the river at a relatively constant rate, the rate being

determined by the particular apparatus being used. For example, when using sprinkler systems a pump supplies water to the sprinkler, and the rate at which it is supplied tends to be constant from day to day, and is determined by the operating specifications of the pump and system. Therefore, pumping rate is relatively constant, while river flows are fluctuating, so the correlation between application rate and river flow is poor if not zero. Under apportionment requested flows for irrigation purposes the rate of river flow would be more closely correlated with the total number of irrigators rather than the withdrawal rate by any individual irrigator. Due to the on/off type of operation of irrigation systems simple averages of boron and TDS concentrations over the irrigation season are more appropriate than flow-weighted averages.

If a flow-weighted water-quality objective is to be applied to the Poplar River Basin, then the more appropriate flow by which to weight the toxicant concentrations would be the rate of irrigation flows (withdrawals), rather than river flows. This procedure would much more accurately represent toxicant dosing rates to the crops, which is the item of concern.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Existing Computational Methods

- There tends to be an inverse relationship between flow in the Poplar River and the concentration of boron and TDS. The IJC recommended five-year moving averages be calculated on data collected during the March to October period, but moving averages are being calculated on the entire 12 months per year. Since flows tend to be lower in winter, and constituent concentrations higher, including November to February data will tend to increase the value of the moving average over that which would be obtained using the shorter time period.

- Regression equations have been estimated for the relationships between specific conductance and each of boron and TDS estimates. The data used were from grab samples which were collected at approximately two-week intervals since mid-1975. These equations were then used to predict daily boron and TDS concentration using daily conductivity estimates. There is a bias between the grab-sample and daily-sample conductivity measures which introduces a bias into the constituent concentration estimates, but this is unlikely to have much impact upon the moving averages.

  We present equations for the relationship between the daily conductance estimates and each of boron and TDS in the grab samples. It is recommended that these, or others derived in the same way be used in future.

- We compared moving averages calculated from both simple concentrations and flow-weighted concentrations. For short duration moving averages (<6 months) there were only slight differences between the two types of average. For long duration averages (1- year, 2-year and 5-year) the flow-

weighted averages tended to be somewhat erratic and primarily sensitive to flow events. The longer the period of the moving average the longer the effect of rare events is retained in the moving-average value.

- Flow-weighted moving averages relate only poorly (if at all) to the toxic effects associated with using river water for irrigation. We recommend flow weighting be discontinued, unless other reasons for retaining it are clearly indicated and they are independent of crop protection.

- If flow weighting is to be retained then in order to minimize the influence of rare, extremely high, flow events we suggest flow-weighted moving averages be calculated using monthly geometric mean flows rather than arithmetic means as is presently done.

- The length of a moving average implies the length of "memory" in the system being analyzed. In the present case using a five-year moving average implies that toxicants in irrigation waters applied five years past are still having an effect upon the crops.

  It seems reasonable that toxicants applied to a field through irrigation water are leached from the field as time passes. If this is the case a "tapered" moving average might be considered in which long past events are given less weight than recent events.

- Moving averages tend to change most in response to periodicities and trends that are of long duration relative to the period of the moving average. The present five-year moving averages will obscure cyclic changes with periods less than five years and will react only slowly to longer term trends. Shorter duration moving averages (one-year or two- year) may be

preferable if mitigative measures are to be initiated based upon the responses of moving averages.

4.2 Appropriateness of IJC Objectives

The concentrations recommended by the IJC as objectives appear to be reasonable in light of the information available at that time. Site specific research they recommended to assess the validity of these values has not been undertaken so we see no impelling reason to question them.

However, flow weighting by river flows does not appear to be a valid approach if crop protection is the main purpose of the concentration objectives. River flows are not related to, or at best only loosely related to, the dosing rate of boron and TDS onto crops via irrigation water. Flow weighting will potentially obscure important concentration relationships in the data. This is particularly true if each irrigator tends to withdraw water from the river at a relatively constant rate (irrespective of date) as would be the case for sprinkler systems operated from an engine driven pump. In this instance flow dependence cancels out of the calculations and simple average concentrations represent the dose applied to the crop.

4.3 Future Actions

Since the inception of the monitoring of the East Fork of the Poplar River the daily concentration of neither boron nor TDS have exceeded the short-term objectives of the IJC. Only rarely were the concentrations above the long-term objective.

The IJC indicated that sufficient frequency of sampling to assess compliance with the objectives was once in 31 days. The observations in the preceeding paragraph arise from a much more intensive sampling program than the IJC required and probably more

intensive analysis than they envisioned.

The existing data are now of sufficient duration and intensity to suggest that the likelihood of the IJC's objectives being exceeded are slim, especially considering these are based upon moving averages and not individual sample values. We therefore recommend that the entire monitoring program be simplified and reduced to that which the IJC deemed sufficient and necessary (i.e. 31 day samples). Likewise the data analyses should be simplified. There will have to be major increases in boron and TDS concentrations in the Poplar River before there is potential for IJC's objectives to be exceeded. Indeed, about 50% of the individual samples would have to exceed the objectives before the specified moving averages would exceed the objective. The frequency of exceedance by grab-sample data can be assessed by the simplest of procedures. Until this frequency approaches 50% there is little practical purpose in devoting any further valuable resources to an intensive sampling program or to the calculation of various statistics such as moving averages. If and when exceedance seems likely, then more intensive data anlayses would be appropriate, and possibly more intensive sampling.

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